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QUARTERLY RELIABILITY

STATUS REPORT (U)

NAS9-150

31 July 1962

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NORTH AMERICAN AVIATION, INC.
SPACE and INFORMATION SYSTEMS DIVISION

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FOREWORD

The Quarterly Reliability Status Report is submitted in accordance with the Apollo documentation requirements delineated in NASA contract NAS9-150, Paragraph 4.5.4.7 of "Project Apollo Spacecraft Development Statement of Work", Part 4, dated 18 December 1961, and MIL-R-27542, Paragraph 5.4.3. The information contained herein covers the period from 1 April through 30 June 1962.

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ILLUSTRATIONS

[redacted]

TABLES

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INTRODUCTION

This document is a continuation of the Reliability Status Report for the Apollo Project as reported in the First Quarterly Reliability Status Report, (S&ID 62-557-1). Significant accomplishments made from 1 April through 30 June are delineated in Section I; planned activities through 30 September 1962 are outlined in Section II.

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I. STUDIES, DESIGN ANALYSES, AND REVIEWS

APOLLO SPACECRAFT RELIABILITY STUDIES

A series of studies was performed during this quarter at the request of MSC, to evaluate the reliability requirements established by NASA for the Apollo Spacecraft. The need for such a study partially resulted in MIT's statement that the apportioned requirement could only be met with considerable redundancy and in-flight maintenance. To date, the study has consisted of comparing the Apollo requirements to those for comparable systems and determining what would be required to meet the reliability requirements of the electronic subsystems.

The subsystems considered were those which contribute to the guidance and control functions of the spacecraft. These include the guidance and navigation (G&N) subsystem, the stabilization and control (S&C) subsystem, the deep space information facility (DSIF), and the telecommunications subsystem. The results of these studies were presented at the following meetings with NASA.

Joint meeting with NASA and MIT at Downey, California, on 18 April 1962

Joint meeting with NASA and MIT at Houston, Texas, from 1 May to 10 May 1962

Meeting with NASA at Houston, Texas, on 13 July 1962.

A summary of the S&ID studies is presented in Table 1. Table 2 presents the results of a comparison of Apollo reliability objectives with those of other manned systems. From these studies, it was concluded that the reliability objectives are reasonable. A paper analysis predicts that they can be met for the electronic subsystems. The results presented by MIT on 1 May 1962 partially agree with this conclusion. They indicated that the G&N subsystem requirement could be met with a degree of in-flight maintenance to be specifically defined at a later date.

The reliability estimates of Table 1 consider, in the first part, the levels of subsystem mission success reliability that can be achieved with unimproved parts and with high-reliability (Minuteman) parts. Here mission success is defined as the probability of completing the lunar landing and returning to earth with no unrepairable failure in the system noted.

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Table 1. Electronic Subsystems Reliability Estimates

Components	Mission Success		Crew Safety	
	Required	Estimated	Required	Estimated
Unimproved Parts				
Guidance and Navigation (G&N)	0.994	0.930	-	-
Stability and Control (S&C)	0.995	0.810	-	-
Telecommunications	0.998	0.975	-	-
Minuteman Parts and Methods				
Guidance and Navigation	0.994	0.994	-	-
Stability and Control	0.995	0.986	-	-
Telecommunications	0.998	0.998	-	-
Combined Parts				
Electronic Systems (unimproved)		0.877		0.9987
Electronic Systems		0.953		0.9998
G&N Unimproved S&C, and telecommunications Minuteman	0.989		0.9998	
Electronic Systems (all Minuteman)		0.991		0.99998

[redacted]

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Table 2. Reliability Comparison of Flight Vehicles

Vehicle	Single Mission		Two-Week Period		
	Mission Success	Crew Safety	Mission Success	Crew Safety	Missions
Apollo	0.90	0.999	0.90	0.999	1
X-15 (1/2 hour flight)	-	0.999	-	0.9992	0.77
F-100 (1-1/2 hour flight)	-	0.9996*	-	0.998*	6
B-70	0.85	0.9995	0.56	0.998	3.6
Bomber (8.9 hour flight)	-	0.9999*	-	0.9998*	1.8
*Field experience					

"Unimproved parts" reliability is based on Polaris data supplied by MIT. A typical component mean-time-between-failures (MTBF) is 1400 hours for the inertial measuring unit (IMU). The Minuteman parts are based on the interim Minuteman reliability objective of 7000 hours MTBF for the system, equivalent to an IMU MTBF of 16,700 hours.

The use of high-reliability parts includes the proper handling and quality control of these parts and the electronic and mechanical stress-analysis techniques employed during Minuteman development. The times employed for the navigation and guidance subsystem were supplied by MIT and were about 25 percent of the mission time. The other systems operated throughout the mission.

These results indicate that only with the high-reliability parts can the G&N subsystem meet its requirements, but that even with these parts, the S&C and telecommunications subsystems are short of the goal and require other approaches for achieving the desired reliability objectives.

The data in the lower third of Table 1 expresses the consideration that for mission success everything must operate on the way to the moon but that failures may occur on the way home. For crew safety it considers that a successful abort may be achieved with failures. This definition dictates the inclusion of various backup modes: man, to control the spacecraft through

[redacted]

reaction controls in the event of an S&C subsystem failure, the inertial reference package (IRP) in the S&C subsystem to back up the IRP in the G&N subsystem, and the DSIF to back up the G&N computer.

Based on the criteria stated above, "crew safety" includes the mission success reliability plus the probability of a successful abort.

The results show that meeting mission success and crew safety requirements are predicated upon high reliability in all electronic subsystems, including the G&N. It is felt that in actual practice the high-reliability parts cannot be used in total but that lack of availability of such parts can be compensated for by the use of low-level redundancy and some in-flight maintenance.

Table 2 compares the Apollo requirements with those of the X-15, F-100 fighter, B-70 bomber, and to the highly developed B-47 and B-52 bombers. The numbers for the Apollo, X-15, and B-70 are theoretical requirements; for the other vehicles, they are results of field experience. The numbers, in view of the Apollo 14-day mission requirements, are given for a single mission and for a two-week period. The last column gives the number of missions normally flown during that period. The results indicate that the Apollo requirements are reasonable.

NASA RECOMMENDED SEQUENCER

A preliminary evaluation of the NASA-recommended design for Apollo propulsion system sequencer is complete. Rocketdyne experience with the Thor and Atlas sequencers, which utilize relays, demanded that solid-state devices be used for the Saturn S-II. Although the vibration and thermal stresses encountered by the S-II unit are greater than Apollo stresses, the higher reliability requirements for Apollo indicate that S&ID should employ solid-state devices on Apollo.

LAUNCH ESCAPE SUBSYSTEM

This section describes Reliability Engineering's launch-escape-subsystem activity during the period April through June. Primary emphasis was placed on the thrust vector control (TVC) nozzle subsystem of the launch escape motor and on the review of subcontractor documentation in order to establish a definitive reliability program. Redirection, involving the elimination of the TVC system, has resulted in a new apportionment of reliability goals for the subsystem. Emphasis during the next report period will be placed on redefining the launch escape subsystem reliability requirements resulting from the addition of a pitch control motor.

Reliability Apportionment

The reliability apportionment of the rocket motors comprising the launch escape subsystem is as follows:

Tower Jettison Motor

The reliability requirement of 0.99995 for the rocket motor has been apportioned for the major portions of the rocket motor as follows:

Motor Parts	Reliability - - Allowed failures per million motors
Squib Initiators	1
Pyrogen Igniters	3
Case	1
Insulation	1
Propellant	1
Fixed Nozzles (2)	43

Reliability of Motor = 0.99995

Launch Escape Motor

The following is a listing of launch escape motor component reliability apportionments:

Component	Reliability - - Allowed failures per million motors
EBW (2)	1000
Pyrogen Igniter	100
Propellent	500
Liner	10
Case	100
Nozzle (4)	100
Total Motor	1112

[redacted]

Pitch Control Motor

The following is a listing of pitch control motor component reliability apportionments:

Component	Reliability - - Allowed failures per million motors
EBW (2)	1000
Pyrogen Igniter	10
Propellent	500
Liner	100
Case	100
Nozzle	100
Total Motor	811

Tower Jettison Motor

Reliability personnel attended a design review held at Thiokol in Elkton, Maryland on June 7 and 8. Of interest to Reliability Engineering was the review of motor case drawings and discussions held on the case configuration. Welding has been eliminated by employing a deep dish forging, and bolting the aft closure in place. The attachment structure is an integral part of the motor case and aft closure. Also, Thiokol was given approval by S&ID to conduct vibration tests, during development, without nozzles or interstage structure.

Review of the drawings and applicable specifications for the igniter assembly, nozzle assembly, and case has been completed. No significant problem areas were found. The major portion of the review activity, such review of processing and inspection procedures, probably will be completed during the next quarter

Failure-Mode Analysis

A preliminary failure mode analysis has been completed. The results of this analysis are summarized in Table 3. It is expected that a detailed analysis will be completed during the next quarter.

Logic Diagram

Figure 1 is the reliability logic diagram of a normal-mission tower jettison. As shown in this diagram, the launch escape motor is redundant

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Table 3. Tower Jettison Motor Preliminary Failure-Mode Analysis

Subsystem	Component	Dominant Failure Mode	Control or Verification
Ignition	EBW	Open or shorted bridge wire	100 percent resistance check in detail and system inspection
	Pyrogen	Case burst	100 percent hydro proof test
		Cracked propellant	100 percent X-ray of grain
Fuel	Solid Propellant	Cracked propellant	100 percent X-ray of grain
		Performance	Batch control testing
Pressure Vessel	Case	Rupture due to wrong material	Material certification Process certification
	Headcap aft bulkhead	Improper heat treat	100 percent hydro proof test
			Development hydro burst
	Insulation	Burn-through due to cracks and voids	100 percent X-ray 100 percent in-process inspection Material certification and verification
	Motor assembly	Pressure leakage due to missing parts, poor seals, etc.	100 percent pressure leak test after assembly
Fixed Nozzles	Nozzle insert	Cracks due to shock or vibration Excessive erosion due to use of wrong material	Development and qualification test 100 percent inspection before and after assembly Material certification, verification, parts identification, and bonded storeroom controls
	Nozzle closure	Pressure leakage	100 percent leak test
	Expansion cone	Cracks and voids	100 percent X-ray
		Excessive erosion due to wrong material	100 percent in-process controls
			Material certification and verification

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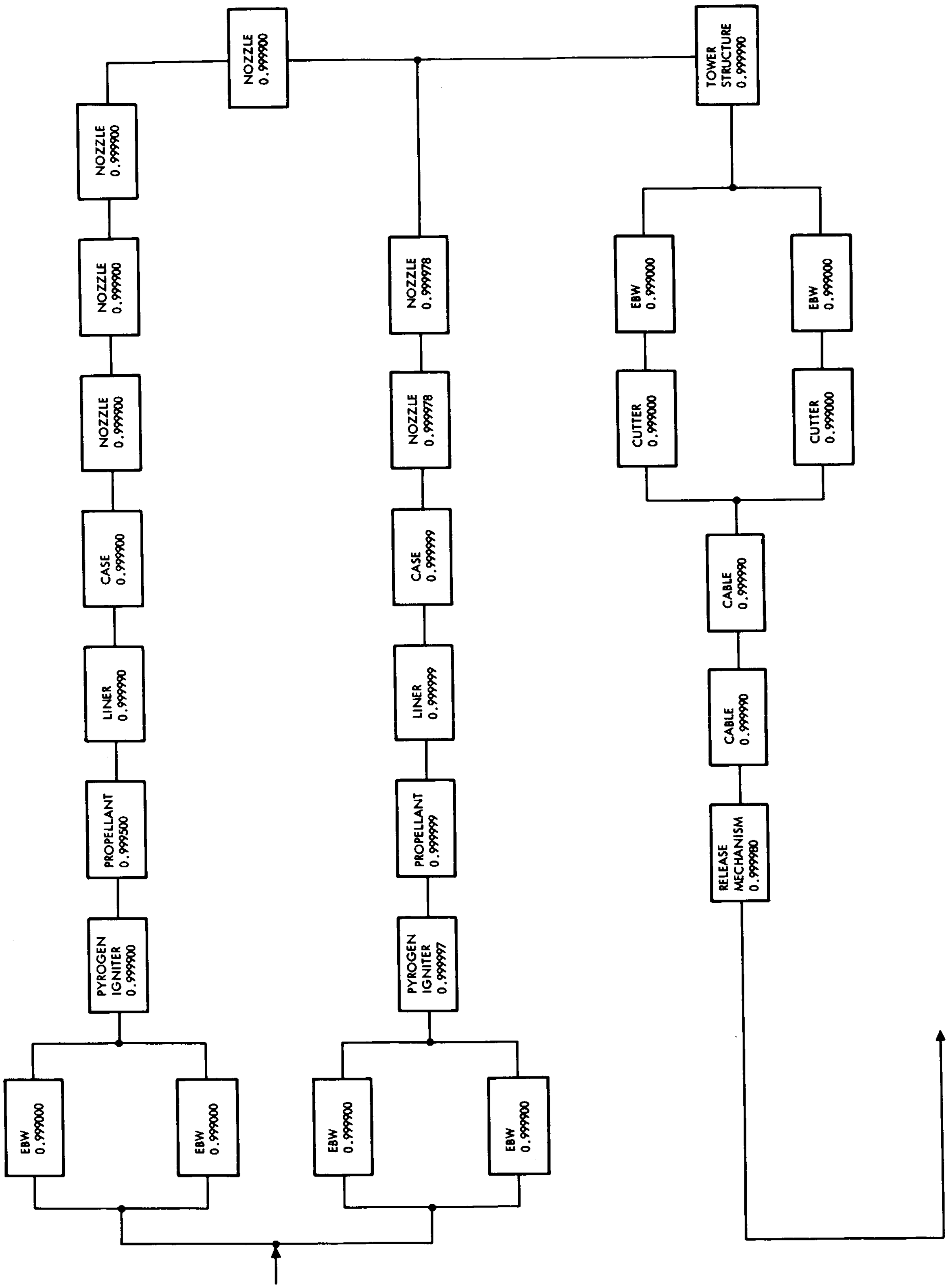

Figure 1. Normal-Mission Tower Jettison Reliability Logic Diagram

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[redacted]

to the tower jettison motor. During tower jettison the pitch control motor remains inoperative.

Launch Escape Motor

Failure-Mode Analyses

During the period covered by this report, failure analyses were completed on all major components. These analyses are shown in Tables 4, 5, and 6.

Table 4 presents the motor case failure-mode analysis. Major emphasis must be placed on material selection, inspection, and quality control in order to maintain the desired reliability.

The failure-mode analysis of the igniter is shown in Table 5. Reliability may be achieved if careful preflight inspections of electrical circuits are performed. Placing an age limit on stored igniters would contribute to the achievement of reliability.

Table 6 shows the grain failure-mode analysis. Reliability is presented as being proportional to the degree of visual inspection; therefore, good quality control and inspection are mandatory.

Logic Diagram

A reliability logic diagram of the launch abort mode is shown in Figure 2. As indicated, a successful abort requires that the launch escape motor and the tower jettison motor function correctly. It is significant to note that a failure of the pitch control motor does not preclude crew safety.

Escape Tower Release

The reliability of two methods of releasing the escape tower was evaluated. Figures 3 and 4 show the two methods and list advantages and disadvantages.

Both methods are acceptable in view of the fact that System A has a reliability of 0.999999 and System B has 0.999996.

Based on the advantages and disadvantages shown in Figures 3 and 4, a decision was reached in favor of the cable-release system.

[redacted]

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Table 4. Launch Escape Motor Case Insulation-Liner Failure-Mode Analysis

Possible Failure	Probable Cause	Reliability Feature	Reliability Focus
Maximum normal pressure rupture case.	o Use of wrong material o Bad welds o Undersized walls o Triaxial stresses (nicks, burrs, scratches) o Local defects (slag, smears)	o 100% proof tests at 2440 psi o High margin of safety o Good practice weld design o Reliability demonstration o Strong quality control and reliability assurance practices o Radiographic inspection	o High cost design due to close tolerances in manufacturing
Heating ruptures case	o Local discontinuities in insulation o Material contamination causing low coefficient o Long motor overload o Poor case insulation liner bonds o Poor thickness control	o Radiographic inspection o Raw material inspection o In-process controls o High margin of safety on insulation thickness	o Quality control and reliability assurance details
Forward closure blows off	o Bolts fail in tension o Bolts elongate and permit gas flow o Bolts overtightened	o High margin of safety o O-ring compression exceeds bolt elongation o Torque control in bolting	o Component type of inspection for bolts (clean threads)

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Table 5. Launch Escape Motor Igniter Failure-Mode Analysis

Possible Failure	Probable Cause	Reliability Feature	Reliability Focus
EBW does not ignite.	o No signal to EBW o Defective EBW	o Redundant EBW's and circuits o Reliable EBW's o Reliable harnesses and connectors	o Prelaunch electrical tests of entire circuit, NAA as well as Lockheed portions
B-KNO_3 pellets fail to ignite.	o Chemical decomposition	o Stable and proven material	o Possibility of one or more of following steps being taken: Dry N_2 flush and hermetic seal on either igniter or container Desiccant in igniter Age limit on use of igniter
Failure to ignite pyrogen	o Resin rich surface o Surface leaching	o Proven material and design in Mercury program	
Structural failure on ignition	o Poor material and/or fabrication	o Large safety margins o Similar designs proven on Mercury and 120-in. ARM programs	
Over ignition - B-KNO_3 pellets powder during shipment and storage	o Pellets rub against each other and against screen	o Design restrains pellets from moving.	
Over ignition - pyrogen provides too much gas.	o Cracks, fissures, or breakup	o Large structural safety margin o X-raying of all units o Successful experience with similar designs	

[redacted]

[redacted]

Table 6. Launch Escape Motor Grain Failure-Mode Analysis

Possible Failure	Probable Cause	Reliability Feature	Reliability Focus
Cracks in star points	o Thermal stresses o Mechanical strains o Aging effects	o Design for structural integrity as well as for ballistic properties	o Surveillance tests to determine aging effects in this particular configuration and set of components
Unbonding because of differential thermal elongation	o Differential thermal strain at grain ends	o Rubber release boot at ends	o Visual inspection
Grain-liner bond failure	o Poor process control o Dirt or grease o Incompatible adhesive	o System proven in Mercury motors	
Poor ballistic reproducibility	o Material variations o Batch variations o Process variations o Process equipment variations	o Extremely close control of all variables o Rigid quality control	

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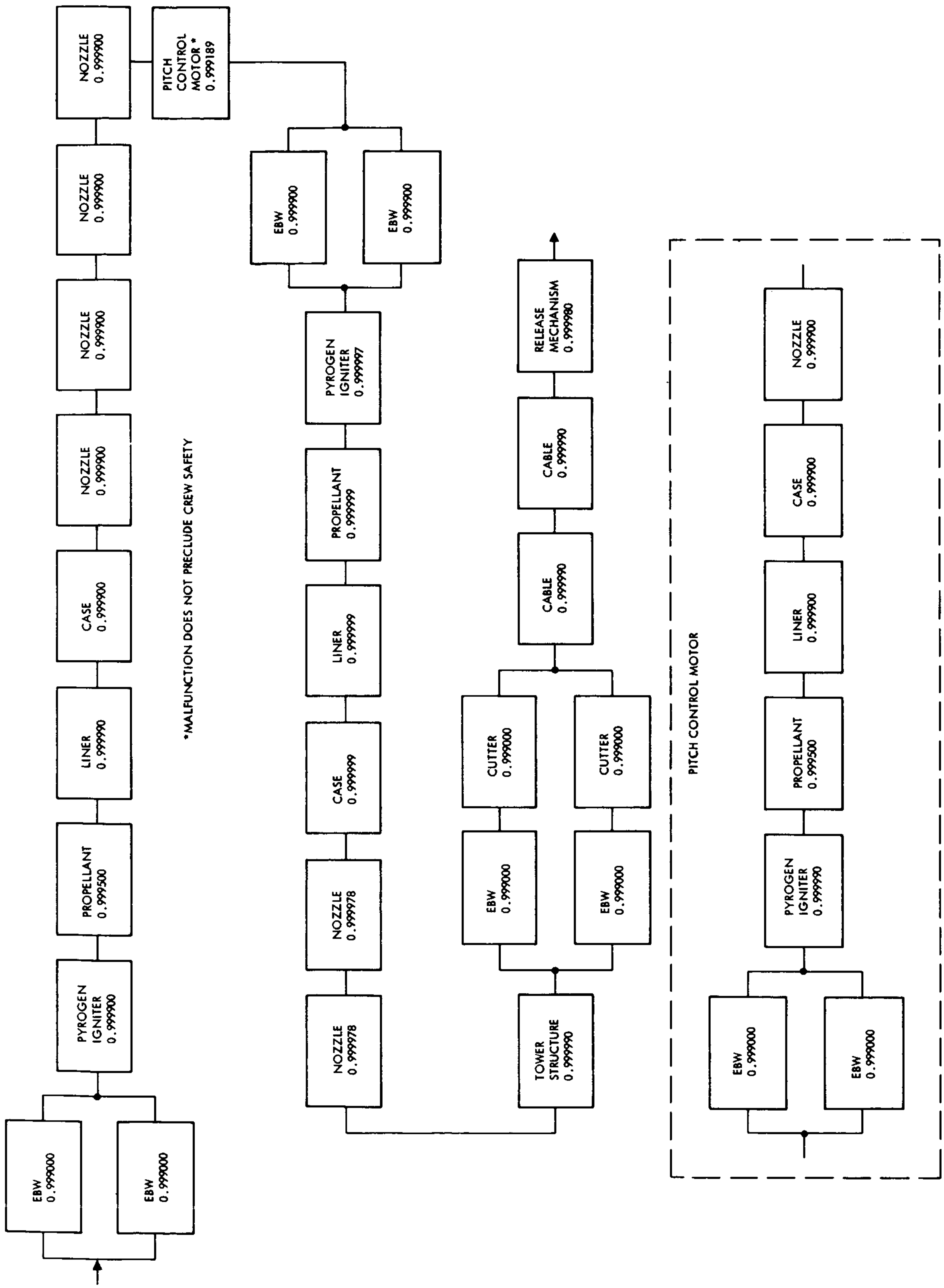

Figure 2. Launch Abort and Tower Jettison Reliability Logic Diagram

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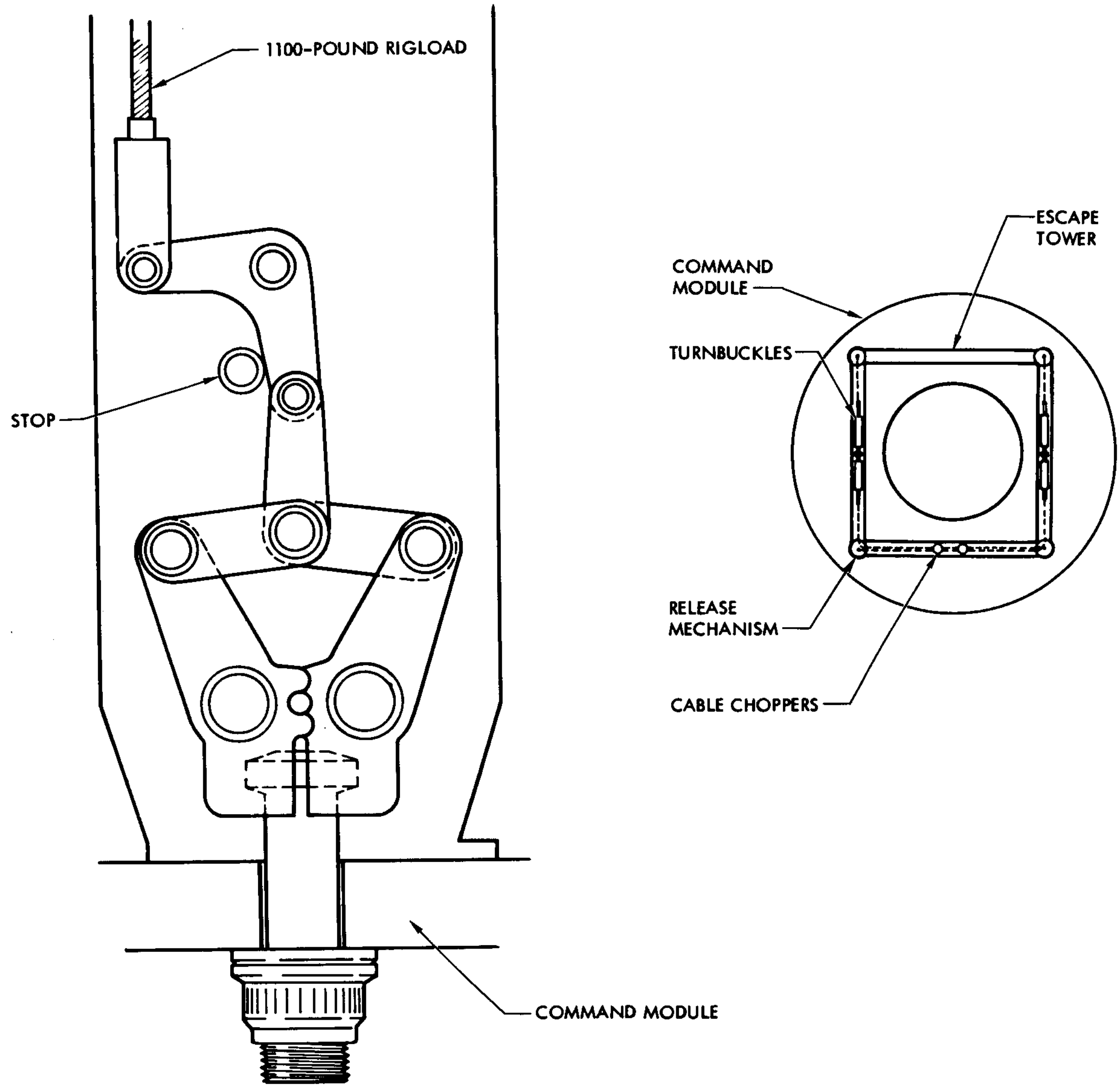

Advantages

Tower is released by either Pyro Cable Chopper.

No chance of mechanism being jammed by flying debris.

Simultaneous release of all four legs from one location.

Disadvantages

Inadvertent firing releases tower from command module; however, the possibility of this happening is very slight.

Figure 3. Escape Tower Release Mechanism, System A - Cable Release

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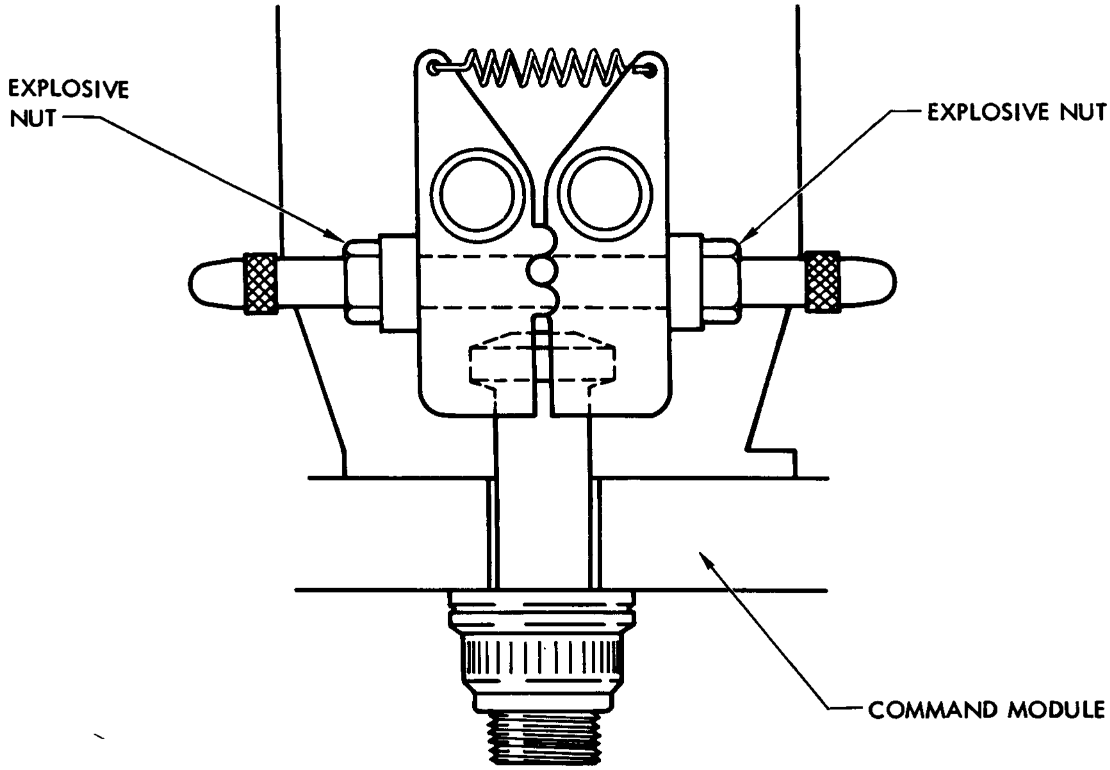

Advantages

Inadvertent firing of one nut would not release the tower, only one leg.

Either explosive nut could release one leg.

Disadvantages

Requires four times as many pyrotechnic devices as cable release system.

Requires weight and complexity of 8 EBW firing units and associated wiring.

One or the other of the explosive nuts would have to work successfully on all four legs in order to release the tower.

In case one leg released inadvertently there is no assurance that the three remaining legs could support the command module in case of an abort.

Chance of jammed mechanism by flying debris.

Nonsimultaneous release of all four legs.

Figure 4. Escape Tower Release Mechanism, System B - Explosive Nut System

[redacted]

Thrust Vector Control (TVC) Design Analysis

Prior to the elimination of TVC, a thorough analysis of the movable nozzle versus fluid injection was completed. Fluid injection and movable nozzles were compared on the basis of reliability allocations. A generic failure rate was assigned each component through use of data from Earles[1]. The same rate was used for similar components in both systems. Only critical components, as shown in Table 7, were used for the analysis.

Table 7. Launch Escape Motor Criticality Analysis

Condition	Abort Mode	Mission Mode (non-abort)
If Malfunction Is Caught in Prelaunch Checkout	Minor*	Minor*
If Malfunction Occurs After Launch	Critical* or major	Major* or minor

*NOTE

Critical: A reliability degrading failure with ramifications in crew safety

Major: A reliability degrading failure which will influence accomplishment of the mission and mission objectives

Minor: A failure with no ramifications in mission success or crew safety; one which influences the basic integrity of the equipment and constitutes a nuisance value or maintenance incident

Mean-time-to-failure was calculated for current time and for six-month and 12-month elapsed times. K factors (a function of application, environment, etc.) were assigned, based on engineering judgment and past experience. Once again the same factors were used for similar components in both

[1] Reference 3

[redacted]

[redacted]

systems. A comparison of Table 8, dealing with fluid injection TVC, and Table 9, dealing with movable nozzle TVC, indicates the advantage of the movable nozzle system.

The relative importance of the movable nozzle in enhancing or degrading the reliability of the over-all system is also indicated. Tables 8 and 9 indicate that there is no degradation of reliability for the movable nozzle even with reliability of a lower order of magnitude. It is noted that for short burning times, at least, the generic reliability of the movable nozzle should be of the same order of magnitude as that of the fixed nozzle.

Table 10, showing operation and logistics mode criteria, was compiled to indicate the various induced environments to which the TVC components would be exposed.

Reliability Prediction of TVC Configurations

Reliability predictions of thrust vector control configurations, utilizing the information shown in Figure 5, (Liquid Injection and Swivel Nozzle Logic Diagram) and Table 11, (Component Failure Rates), yielded the following results:

System Rating (Numerical Results)

Secondary injection (on-off, 2-nozzle control)	0.9953
Swivel nozzle (2-nozzle control)	0.9890
Secondary injection (2-nozzle proportional control)	0.9888
Swivel nozzle (4-nozzle control)	0.9803
Secondary injection (4-nozzle proportional control)	0.9692

The criteria for establishing the TVC predictions are as follows:

All four nozzles must operate.

The operating time during the mission is 10 minutes.

The environmental factor (k) is equal to 1,000.

Standard failure rate data were used in predicting the system reliability.[1]

[1] Reference 4

[redacted]

[redacted]

Table 8. Launch Escape Motor Fluid-Injection Thrust Vector Control

Part	Function	Criticality[1]	Quan/Unit	Mean Failure Rate 10^6 hrs	Engr Judgment Factor			Total Adjusted Failure Rate		
					Now	6 mo	12 mo	Now	6 mo	12 mo
N_2 Torus	Store N_2 at 4500 psi	Critical	1	0.10	1000	200	10	100.0	20.0	1.0
N_2 Fill Fitting	Fill N_R torus	Minor	1							
N_2 Pressure Sense	Sense N_2 pressure	Major	1	35.0	75	10	1	2,625.0	350.0	35.0
Check Valve	Seal N_2 system	Critical	1	8.1	50	1	1	405.0	8.1	8.1
Orifice	Control press transfer	Critical	1	0.15	10	1	1	1.5	0.15	0.15
Relief Valve	Control system pressure	Critical	1	5.7	10	1	1	57.0	5.7	5.7
Freon Torus	Store freon	Critical	1	0.10	1000	200	10	100.0	20.0	1.0
Bladder	Separator	Critical	1	500.0	100	10	1	50,000.0	5,000.0	500
Freon Fill Fitting	Fill freon torus	Minor	1							
Check Valve	Isolate freon permit GSE testing	Minor	1							
GSE Connector	GSE testing	Minor	1							
Injector Valve	Meters freon	Critical	16	60.0	100	50	10	96,000.0	48,000.0	9,600.0
Filter	Filter servo fluid	Critical	4	0.3	50	1	1	60.0	1.2	1.2
Servo Valve	Control injector valves	Critical	4	6.9	200	50	1	5,520.0	1,380.0	27.6
Nozzle Attachment	Hold injector valves	Critical	16	20.0	50	1	1	16,000.0	320.0	320.0
Fixed Nozzle	Directs exhaust	Critical	4	500	10	1	1	20,000	2,000	2,000
Total Failure Rate								190,869	57,105	12,500

[1]For definitions, see note, Table 6.

Criticality

Condition	Abort	Nonabort
If caught in GSE	Minor	Minor
If malfunc after launch	Critical	Major

[redacted]

[redacted]

Table 9. Launch Escape Motor Movable-Nozzle Thrust Vector Control

Part	Function	Criticality[1]	Quan/Subsystem	Mean Failure Rate	Engr Judgment Factor			Total Adjusted Failure Rate		
				10^6 hrs	Now	6 mo	12 mo	Now	6 mo	12 mo
N_2 Fill Fitting	Pressurize reservoir	Minor	1							
Reservoir	Hold hydraulic fluid	Critical	1	20.0	10	1	1	200.0	20.0	20.0
Bladder	Separator	Critical	1	20.0	10	1	1	200.0	20.0	20.0
High-Fill Fitting	Fill reservoir	Minor	1							
Oil Press Sense	Sense oil pressure	Major	1	35.0	75	10	1	2,625.0	350.0	35.0
Check Valve	Seal hydraulic system	Critical	1	0.6	1	1	1	—	—	—
Check Valve	Permit GSE test	Minor	1							
GSE Connect	For GSE test	Minor	1							
Filter	10 μ filtration	Critical	4	0.3	50	1	1	60.0	1.2	1.2
Check Valve	Prevent drift	Major	4	5.0	50	1	1	1,000.0	20.0	20.0
Servo Valve	Control actuator	Critical	4	6.0	200	50	1	5,520.0	1,300.0	27.6
Actuator	Movable nozzle	Critical	4	12.5	10	1	1	500	50.0	50.0
Movable Nozzle	Deflect exhaust	Critical	4	500	100	10	5/1	200,000	20,000	10,000
Total Failure Rate								215,505	21,841	10174/2174

[1] For definitions, see note, Table 6

[redacted]

[redacted]

Table 10. \Launch Escape Motor Operational and Logistics Modes Criteria - Movable Nozzle

Item	Storage (5 years)	Handling and Assembly	Transport	Prelaunch	Functional	
					Abort	Nonabort
N_2 Fill Fitting	Leak, corrosion, contamination	Ease of assembly	Package for rough handling, natural environment	Ease of replacement clean replace	*	*
Reservoir	Corrosion, creep, stress	Ease of assembly	Package for rough handling, natural environment	Ease of replacement clean replacement	Pressure and leak integrity	Must not blow
Bladder	Chemical stability, temperature dimensional stability and collapses	Sharp edges ease of assembly	Package for rough handling, natural environment	Pressure integrity leak integrity	Pressure and leak integrity	*
Oil Fill Fitting	Leak, corrosion, contamination	Ease of assembly	Package for rough handling, natural environment	Ease of replacement clean replace	*	*
Oil Pressure Sensor	Leak, corrosion, contamination	Easy installation	Package for rough handling, natural environment	Accuracy	*	*
Check Valve	Corrosion, temperature humidity, electrical continuity	Safety, leak integrity, electrical continuity	Package for rough handling, natural environment	Ease of replacement	Must function	*
GSE Connect	Leak, corrosion, contamination	Ease of assembly	Package for rough handling, natural environment	Ease of replacement clean replace	*	*
Filter	Corrosion, contamination	Easy, leak integrity, foolproof	Package for rough handling, natural environment	No leaks at connection	Functions without leaks	*
Servo Valve	Dust, dirt, oil, corrosion, leak	Ease of assembly polarity	Package for rough handling, natural environment	Ease of replacement	Functions as designed	*
Actuator	Corrosion, creep residual stress	Ease of assembly polarity	Package for rough handling, natural environment	Ease of replacement	Functions as designed	*

*Does not apply

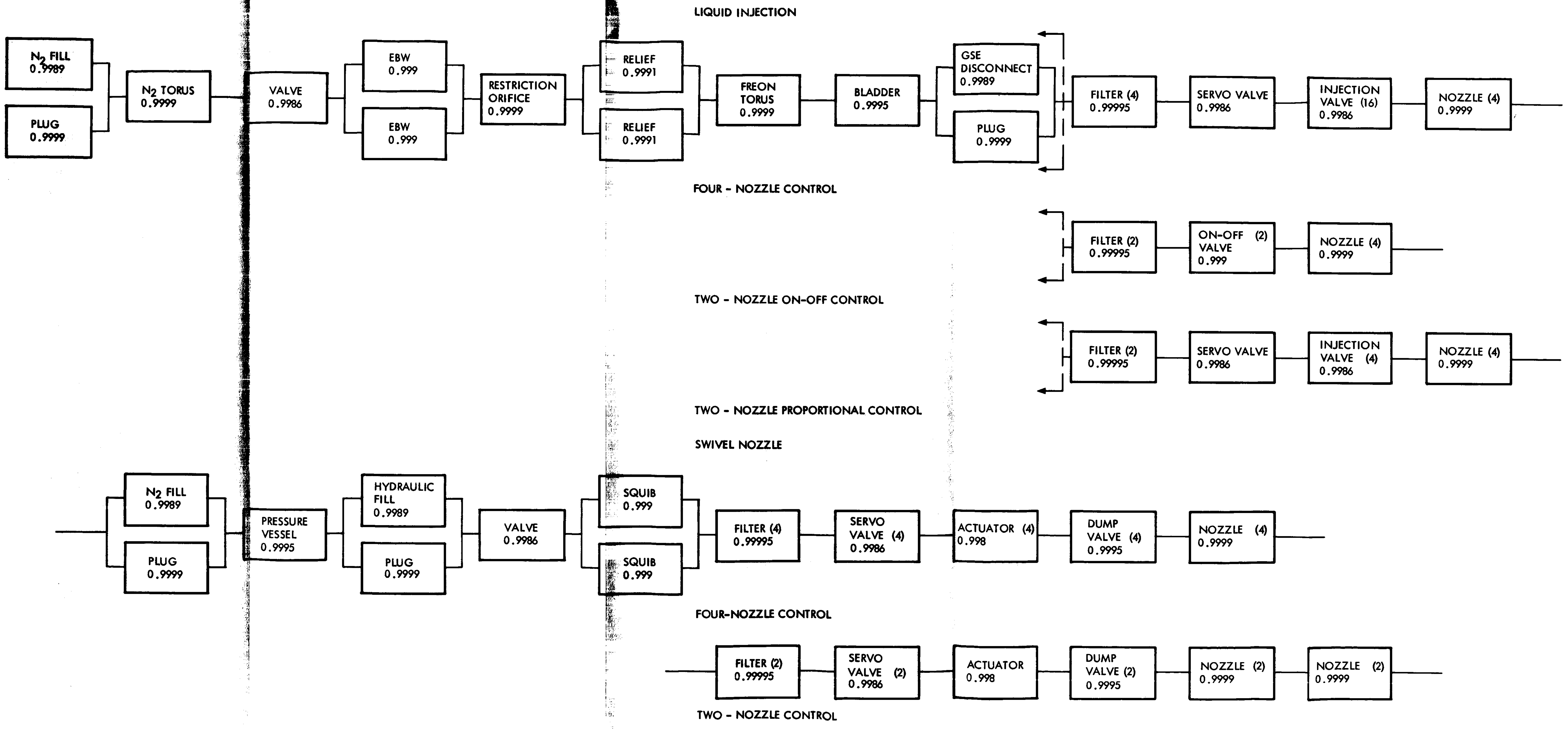

Figure 5. Proposed Thrust Vector Control Reliability Logic Diagram

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Table 11. Thrust Vector Control Methods Component-Failure Rates

Liquid Injection Components	Reliability*	Swivel Nozzle Components	Reliability*
N_2 fill valve	110	N_2 fill valve	110
Plug	10	Plug	10
Freon valve	140	Pressure valve	50
Squib	10	Hyd. fill	110
Restriction orifice	10	Hydraulic valve	140
Relief valve	90	Squib	100
Freon torus	10	Filter	5
N_2 torus	10	Servo valve	140
Freon bladder	50	Actuator	200
Disconnect	110	Dump valve	50
Filter	5	Swivel nozzle	50
Servo valve	140		
Injection valve	140		
Nozzle	10		
On-off valve	100		

*The component reliability figures, expressed as allowed failures per 10^5 assemblies, were arrived at from failure rate data contained in References 3, 6, and 10.

[redacted]

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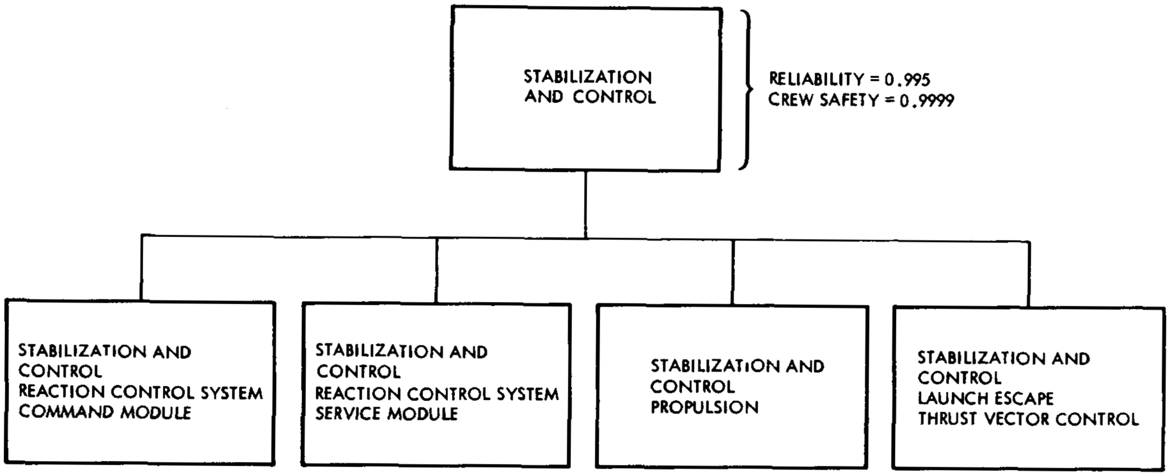
TVC Stabilization and Control Subsystem Reliability Apportionment

This Apportionment (Figure 6) was made with the assumption of a booster reliability of 95 percent, as indicated by NASA in the Apollo Work Statement. [1]



First-stage booster reliability (R_1)	0.983
Second-stage booster reliability for 10-second operation (R_2)	0.995
	$R_1 \times R_2 = 0.978$

Figure 6. TVC Stabilization and Control Subsystem Block Diagram

The predicted booster failure rate is 22 booster failures per thousand missions. This representative quotient indicates that the launch escape system electronics, will be required to operate 22 times per thousand missions.

From the apportioned crew safety of 0.1 fatalities per thousand missions for the entire stabilization and control system, 0.01 fatalities per thousand missions have been apportioned to launch escape TVC electronics.

[1] Reference 5

[redacted]

Using the preceding values, the reliability goal for launch escape electronics was established as follows:

$$\frac{1,000 \text{ missions}}{22 \text{ aborts}} \times \frac{0.01 \text{ fatalities}}{1,000 \text{ missions}} = \frac{0.01 \text{ fatalities}}{22 \text{ aborts}}$$

or

$$R = 1 - \frac{0.01}{22} - 0.9955 - 4.5 \text{ failures per thousand aborts.}$$

In order to enhance crew safety, the following criterion has been established for the launch escape electronics:

> 4.05 failures per thousand aborts of the allowable 4.5 failures per thousand aborts are to be fail-safe in a neutral position.

Escape Rocket Case

Reliability tests of the escape rocket case subsystem are based on a modification of Lusser's principles. A reliability boundary has been established, based on pressure data from the Mercury escape program. A proof pressure test is specified at a considerably higher pressure than the limit load. For the Apollo launch escape rocket the proof pressure is a minimum of 10 sigma over the mean limit load.

The numerical definition of the minimum safety margin for the launch escape rocket is illustrated in Figure 7. The reliability boundary or limit load is converted to an equivalent pressure so that it can be correlated with the 100 percent proof pressure requirements for the case. The reliability boundary pressure is the summation of the equivalent pressures from the external bending stress, the hoop stress, and standard deviation of pressure (for batch-to-batch variation) based on previous test work. The case pressure test of 2440 psi will screen out all substrength cases due to design, manufacturing, or material discrepancies. The safety margin is defined as the number of standard deviations of pressure between the reliability boundary and the proof test. The maximum pressure from each of the 28 qualification-reliability tests will be plotted on this chart to demonstrate the actual reliability achieved. In addition to the 28 qualification-reliability tests, some motors from the development program and tests performed by NAA will be used to demonstrate reliability.

Propellant-Ignition Subsystem

Reliability demonstration of the propellant ignition subsystem will consist of 28 qualification-reliability static firing tests. Propellant

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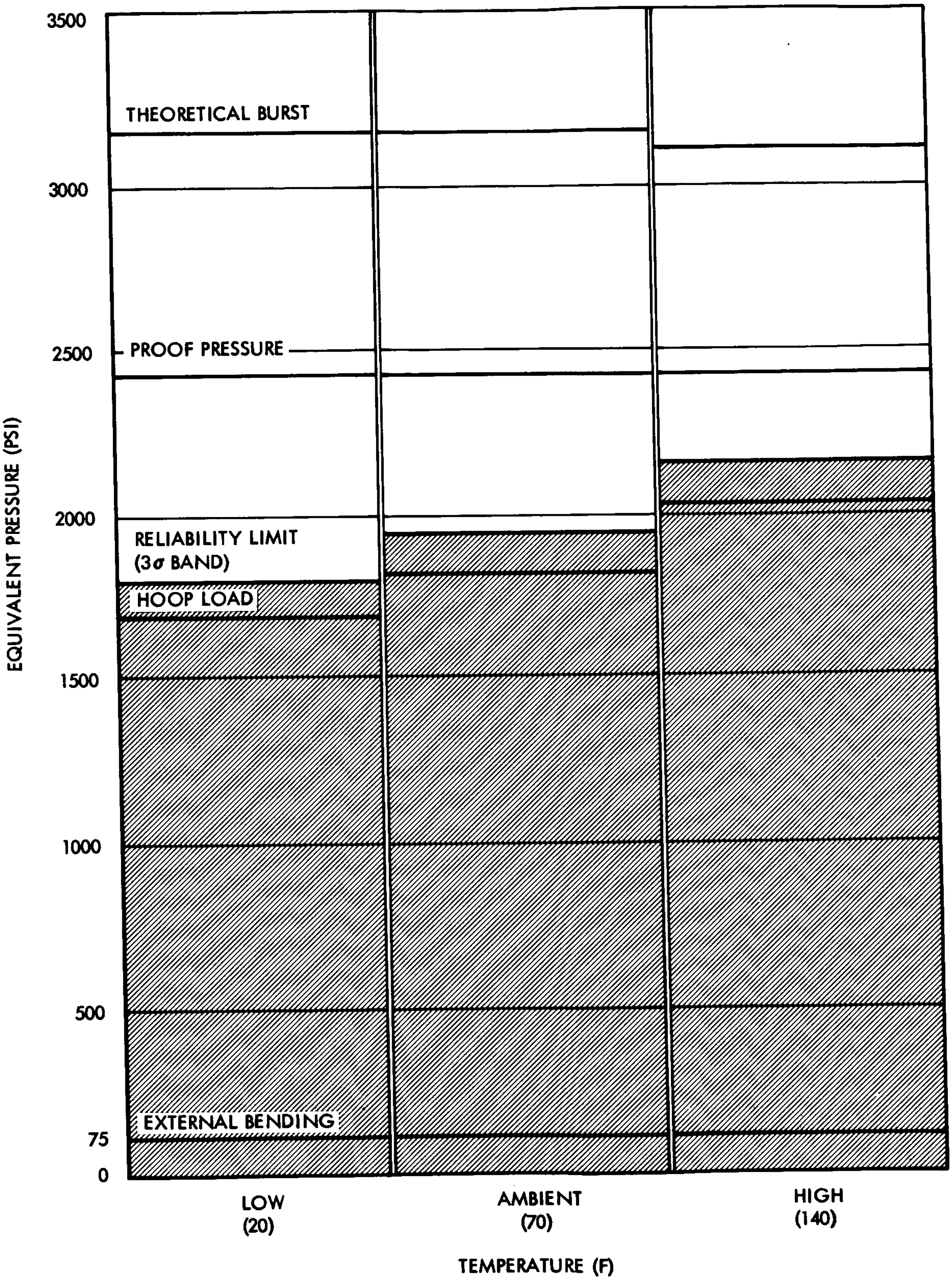

Figure 7. Launch Escape Motor Safety Margin Demonstration

ingredients will be subject to chemical, ballistic, and physical property tests on each lot of raw material and on each batch of propellant to determine whether the batch meets the requirements of the Apollo specification. Each finished grain will be subjected to radiographic and visual inspections. Grains which exhibit voids, cracks, or surface defects which could affect the performance of the Apollo launch escape motor will be rejected. Only those motors which meet the stringent quality control requirements will be acceptable for use during this program. These procedures will be continued on subsequent production articles to ascertain that future manufacture of rocket motors will meet the extremely high reliability requirements of the motors manufactured for the development program.

ENVIRONMENTAL CONTROL SUBSYSTEM (ECS)

A preliminary analysis of the environmental control subsystem (ECS) has been completed with logic diagrams depicting the series parallel relationship of ECS components and modes of operations with respect to successful and safe performance. The evaluations of failure modes and effects on failure rates of each component forms an integral part of this reliability analysis.

Flight Module Apportionment

The ECS apportionment contained in Table 12, represents a first order analysis of the subject system based upon the following assumptions.

The logic diagrams in figures 8 through 14 have been modified such that (1) no redundancy is considered; (2) normal operation and normal conditions are assumed (no crew safety operation or emergency conditions); (3) manual overrides are not separated, the reliability of the crew properly performing the required operation is assumed to be one; and (4) only space operation is considered.

Also these additional assumptions apply: a 400-hour mission time with a a reliability of 0.9935 is assumed. The accessibility index is assumed to be one, since no maintenance is permitted. The failure rate assigned to each component includes the associated joints or fittings required to install or mount that component. The failure rates listed and associated MTBF's include the integrated environmental effects for the total mission time (these are not generic failure rates).

Ground Support Equipment Apportionment, Water-Glycol Unit

The analysis (Table 13) of the components for the Water-Glycol Unit (GSE) is based upon relative complexity factors. The resultant failure rates, equivalent MTBF's, and equivalent cycles per component are the

[redacted]

Table 12. Preliminary Apollo ECS Reliability Apportionment (First Order Analysis)

Part No.	Item Description	Equivalent Series Quantity	Failure Rate Percent λ (1000 hrs)	Equivalent Mean Time Between Failures (*Million hours)	Equivalent Cycles	Assumed Usage (Cy/hr)
a*	Suit/Cabin Air Circuit					
1.1	Valve, check, raspberry, N/C	2	0.0025	39.7		
1.2	Heat exchanger, air/air regen. X flow	1	0.0008	119		
1.3	Valve, check, dual, butterfly, N/C	1	0.0067	14.9	298,000	1/50 hrs
1.4	Valve, limiting and manual shutoff, N/O	4	0.0042	24		
1.5	Connector, N/O	3	0.0008	119		
1.6	Valve, check, flapper, N/C	4	0.0067	14.9		
1.7	Connector; orifice, N/C	3	0.0050	19.8		
1.8	Debris trap, screen filter	1	0.0008	119		
1.9	Catalytic filter	1	0.0050	19.8		
1.10	Compressor, centrif., 10K rpm	1	0.0462	2.16		
1.11	Valve, check, raspberry, N/C	3	0.0025	39.7		
1.12	Valve, manual shutoff, N/O	1	0.0042	24	2,000,000	1/12 hrs
1.13	Valve, check, raspberry, N/C	1	0.0025	39.7	3,310	1/12 hrs
1.15	CO_2 and odor adsorber	1	0.0034	29.8		
1.16	Valve, pressure relief w/man. ovr'd. N/C	1	0.0126	7.93		
1.17	Switch, rotary, four-position assembly	1	0.0084	11.9	298,000	1/400 hrs
1.18	Valve, electr. act. contr. w/man. ovr'd.	1	0.0420	2.38		
1.19	Heat exchanger; glycol/air; X flow	1	0.0008	119		
1.20	Heat exchanger, water/air X flow	1	0.0008	119		
1.21	Valve, diverter, manual	1	0.0042	24		
1.22	Water separator (w/shutoff valve & actu.)	1	0.0840	1.19	2,380,000	2/hr(act)
1.24	Temperature control, magnetic amplifier	1	0.0336	2.98		
1.25	Temperature selector, rheostat	1	0.0067	14.9		
1.28	Temperature control, magnetic amplifier	1	0.0336	2.98		
5.5	Valve, elect. act. contr. w/man. ovr'd.	1	0.0420	2.38		
5.13	Valve, check, quad. assembly, N/O	2	0.0084	11.9	23,800,000	2/hr.
7.1	Sensor, air pressure	*	*	*		
7.3	Sensor, air temperature	1	0.0042	24		
7.6	Sensor, pressure differential	*	*	*		
7.7	Sensor, pressure differential	*	*	*		
7.9	Sensor, air temperature	*	*	*		
7.10	Sensor, voltage indication	*	*	*		
7.11	Sensor, air temperature	1	0.0042	24		
a*	Reference Figure 8					
b*	Water - Glycol Circuit					
2.1	Valve, check, ball, N/C	4	0.0042	24		
2.2	Valve, relief, ball, N/C	1	0.0084	11.9		
2.3	Disconn., self-sealing (2 conn.)	(2)	0.0084	11.9	24,000	1/500 hrs
2.4	Valve, manual shutoff, N/O	3	0.0042	24	240,000	1/100 hrs
2.5	Valve, check, ball, N/O	2	0.0042	24		
2.6	Heat exchanger, water - glycol, X flow	1	0.0008	119		
2.7	Reservoir, glycol, spring op.	1	0.0017	59.5		
2.8	Valve, manual shutoff, N/O	1	0.0042	24		
2.9	Valve, manual shutoff, N/O	1	0.0042	24		
2.10	Valve, electr. act. contr., N/O	1	0.0378	2.64		
2.12	Temperature control, magnetic amplifier	1	0.0336	2.98		
2.13	Valve, dual electr. act. contr. w/manual override	1	0.0758	1.32		
2.14	Valve, check, ball, N/C	3	0.0042	24		
2.15	Pump, glycol, gear, 6Krpm	1	0.0420	2.38		
2.16	Switch, rotary, 4 position assembly	1	0.0084	11.9		

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Table 12. Preliminary Apollo ECS Reliability Apportionment (First Order Analysis) (Continued)

Part No.	Item Description	Equivalent Series Quantity	Failure Rate Percent λ (1000 hrs)	Equivalent Mean Time Between Failures (*Million hours)	Equivalent Cycles	Assumed Usage (Cy/hr)
b*	Water - Glycol Circuit (Continued)					
2.19/ 5.6	Valve, dual, elect. act. contr. w/manual override	(1)	0.0758	1.32		
2.20	Valve, electr. act. contr. N/C	4	0.0378	2.64		
2.22	Temperature control, magnetic amplifier	1	0.0336	2.98		
2.24	Disconn., self-sealing, assembly	1	0.0084	11.9		
3.5	Temperature selector, rheostat	1	0.0067	14.9		
3.7	Temperature, contr., mag. amp.	1	0.0336	2.98		
8.6	Sensor, glycol temperature	1	0.0042	24		
8.9	Sensor, glycol temperature	1	0.0042	24		
9.5	Sensor, air temperature	1	0.0042	24		
9.6	Sensor, air temperature	1	0.0042	24		
b*	Reference Figure 9					
c*	Pressure and Temperature Control System					
3.1	Valve, dual regulator and relief, manual override	1	0.0252	3.97		
3.2	Heat exchanger, air/glycol, X flow	1	0.0008	119		
3.9	Snorkel, inflow (required to operate post-landing only)	*	*	*		
3.10	Valve, manual shutoff, N/C	1	0.0042	24		
3.12	Valve, manual shutoff, N/C	1	0.0042	24		
3.14	Valve, diverter, manual	1	0.0017	59.5		
3.17	Switch, rotary, 3 position, assembly	1	0.0084	11.9		
3.18	Blower, fan, 6K rpm	2	0.0420	2.38		
3.19	Valve, relief, ball, N/C	1	0.0084	11.9		
3.20	Valve, regulator, dual, flow limiting, manual override	1	0.0168	5.95		
3.22	Valve, regulator, quad. assembly	1	0.0168	5.95		
c*	Reference Figure 14					
d*	P and T Control System - N_2 Supply					
2.3	Disconnect, self-sealing (1 conn.)	1	0.0084	11.9		
10.2	Sensor, N_2 flow	*	*	*		
10.3	Sensor, N_2 pressure	*	*	*		
10.5	Sensor, command module total pressure	*	*	*		
d*	Reference Figure 13					
e*	O_2 Supply Circuit					
1.22	Water/separator with shutoff valve and actuator		0.0840	1.19		
4.1	Valve, electr. act. contr. dual assembly	1	0.0379	2.64		
4.2	Pressure contr., mag. amp. assembly	1	0.0336	2.98		
4.11	Valve, relief, ball, N/C	1	0.0084	11.9		
4.15	Valve, manual shutoff, N/C	2	0.0042	24		
4.16	Valve, demand pressure and relief, N/O	1	0.0420	2.38		
4.17	Valve, manual shutoff, N/C	1	0.0042	24		
4.19	Valve, regulator, quad. assembly	1	0.0168	5.95		
4.22	Valve, regulator (dual), man. override	1	0.0168	5.95		

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Table 12. Preliminary Apollo ECS Reliability Apportionment (First Order Analysis) (Continued)

Part No.	Item Description	Equivalent Series Quantity	Failure Rate Percent λ (1000 hrs)	Equivalent Mean Time Between Failures (*Million hours)	Equivalent Cycles	Assumed Usage (Cy/hr)
e*	O_2 Supply Circuit (Continued)					
2.3	Disconnect., self-sealing (1 conn.)	1	0.0084	11.9		
5.11	Valve, regulator and relief, man. override	1	0.0252	3.97		
5.20	Valve, regulator and relief, man. override	1	0.0252	3.97		
7.2	Sensor, O_2 partial pressure	1	0.0168	5.95		
7.6	Sensor, pressure differential	*	*	*		
9.2	Sensor, O_2 flow rate	*	*	*		
9.3	Sensor, O_2 pressure (entry)	*	*	*		
9.4	Sensor, position	*	*	*		
9.8	Sensor, O_2 pressure	*	*	*		
10.5	Sensor, command module total pressure	*	*	*		
	O_2 Re-entry Supply					
4.6	Tank, oxygen storage, 7500 psi	1	0.0017	59.5		
4.7	Valve, manual shutoff, high pressure, N/C	1	0.0084	11.9		
4.8	Valve, manual shutoff, high pressure, N/C	1	0.0084	11.9		
4.9	Valve, regulator, high pressure, N/C	1	0.0210	4.76		
4.10	Valve, check, ball, N/O	1	0.0042	24		
	O_2 Back Pack Supply					
4.13	Valve, Relief and manual shutoff, N/C	1	0.0126	7.93		
4.14	Cap, sealing	1	0.0008	119		
2.3	Disconnect, self-sealing (1 conn.)	1	0.0084	11.9		
e*	Reference Figure 10					
f*	Water Supply					
5.1	Disconnect, self-sealing, N/C	1	0.0084	11.9		
5.2	Valve, check, preset, N/C	1	0.0067	14.9		
5.3	Valve, shutoff, manual, N/C	(2)	0.0042	24	480,000	
5.4	Valve, three-way, manual, N/O	1	0.0067	14.9		
5.8	Valve, shutoff, manual, N/C	1	0.0042	24		2/hr
5.9	Valve, check, ball, N/C	1	0.0042	24		
5.10	Water tank, bladder	1	0.0126	7.93		
5.14	Heat exchanger, glycol/water, // flow	1	0.0008	119		
5.15	Water tank, bladder	1	0.0126	7.93		
5.16	Valve, three-way, manual; N/O	1	0.0067	14.9		
5.17	Valve, shutoff, manual, N/C	1	0.0042	24		
2.3	Disconnect, self-sealing (1 conn.)	1	0.0084	11.9		
11.2	Sensor, water quantity	*	*	*		
f*	Reference Figure 12					
g*	Air Lock					
6.1	Valve, shutoff, manual	1	0.0042	24	480,000	1/50
6.2	Valve, shutoff, manual	1	0.0042	24		1/50
6.3	Valve, shutoff, manual	1	0.0042	24	480,000	1/50

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Table 12. Preliminary Apollo ECS Reliability Apportionment (First Order Analysis) (Continued)

Part No.	Item Description	Equivalent Series Quantity	Failure Rate Percent λ (1000 hrs)	Equivalent Mean Time Between Failures (*Million hours)	Equivalent Cycles	Assumed Usage (Cy/hr)
g*	Air Lock (Continued)					
6.4	Valve, shutoff, manual	1	0.0042	24	480,000	
10.4	Sensor, airlock pressure	*	*	*	480,000	1/50
g*	Reference Figure 11					

* - These components are to be used in conjunction with display instrumentation and reliability will be apportioned when this data is available.
N/C - Normally closed
N/O - Normally open
X flow - Cross flow
// flow - Parallel flow

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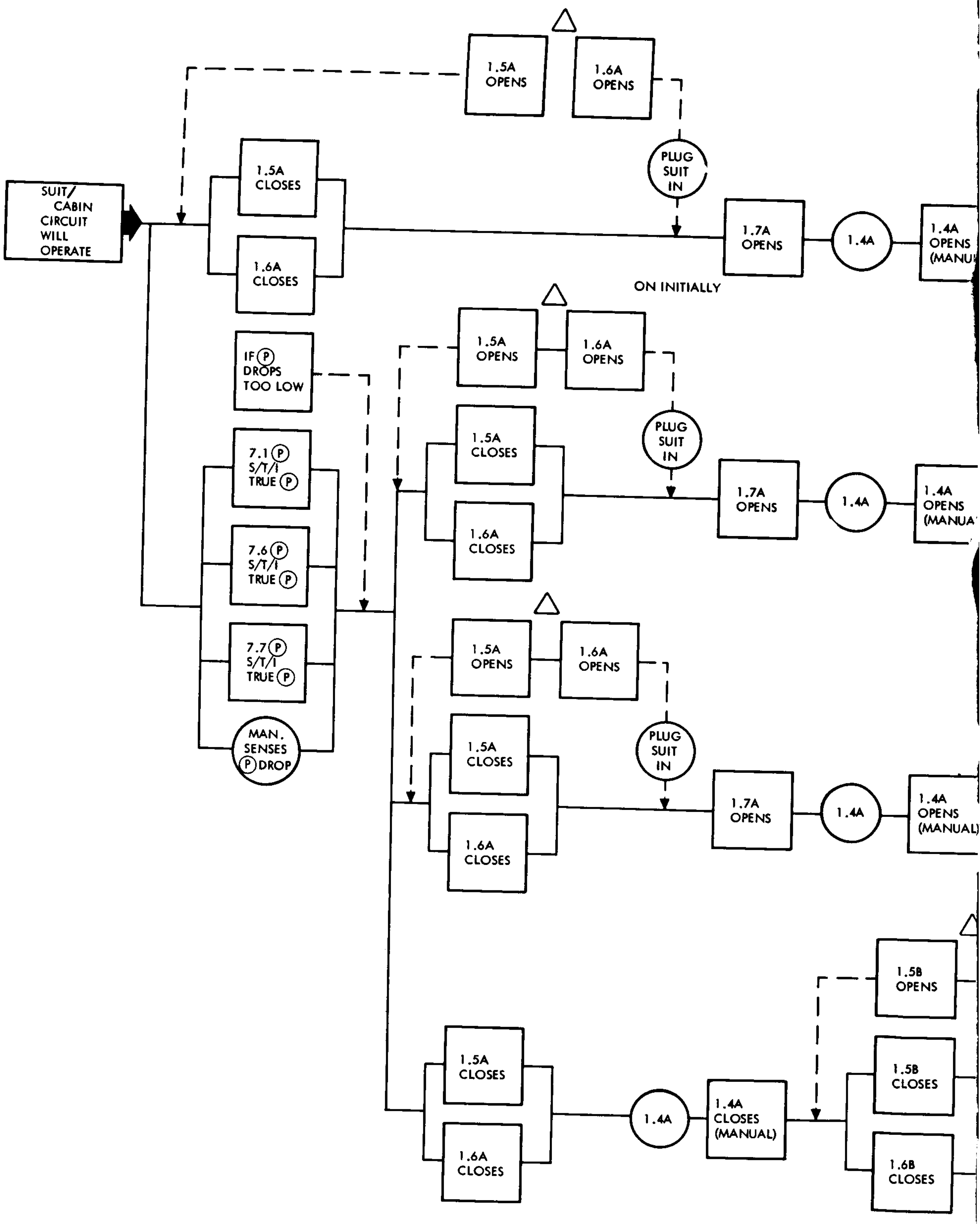

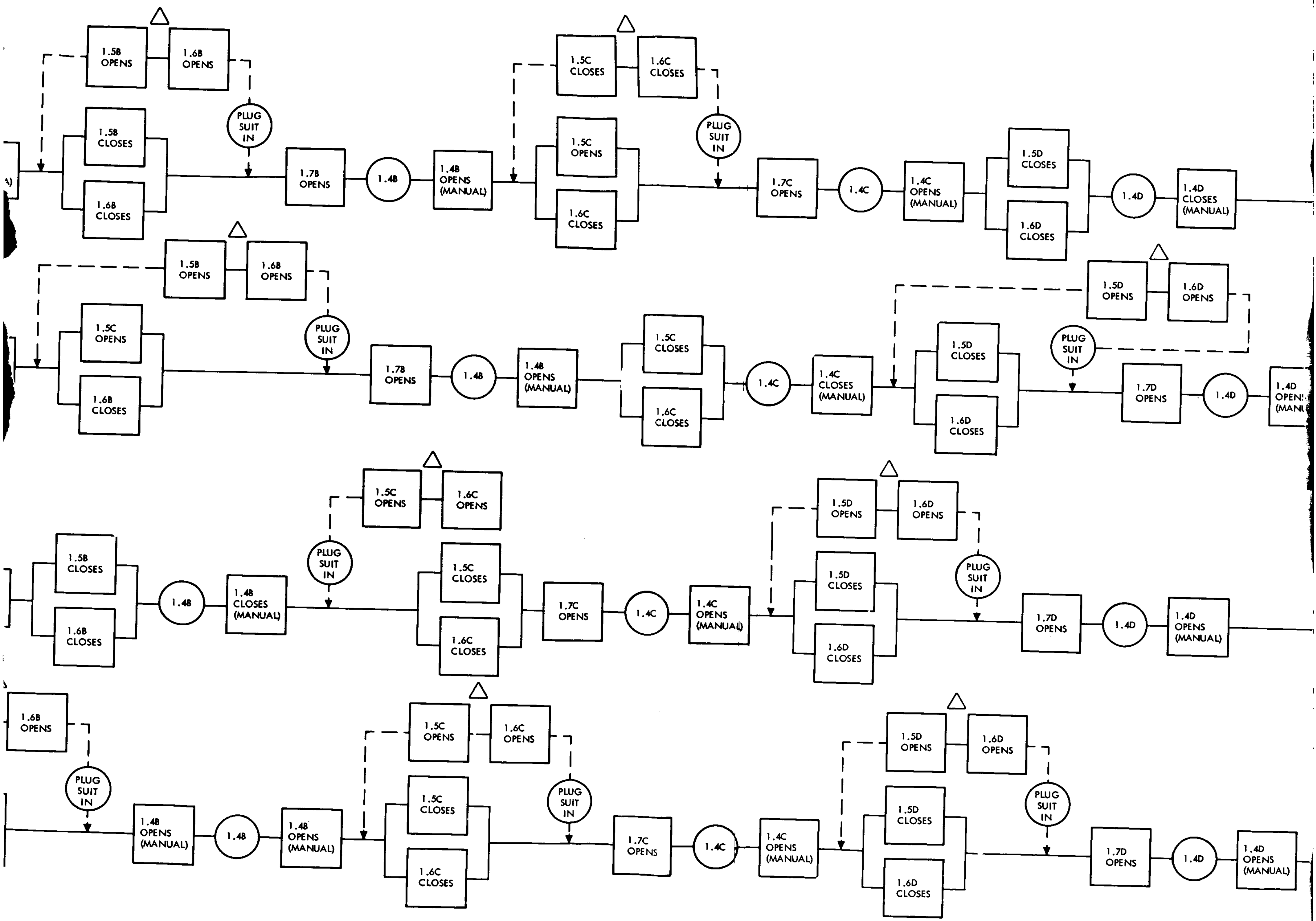

1.5B OPENS
1.6B OPENS
PLUG SUIT IN
1.5B CLOSES
1.6B CLOSES
1.7B OPENS
1.4B
1.4B OPENS (MANUAL)
1.5C CLOSES
1.6C CLOSES
PLUG SUIT IN
1.5C OPENS
1.6C CLOSES
1.7C OPENS
1.4C
1.4C OPENS (MANUAL)
1.5D CLOSES
1.6D CLOSES
1.4D
1.4D CLOSES (MANUAL)
1.5B OPENS
1.6B OPENS
PLUG SUIT IN
1.5C OPENS
1.6B CLOSES
1.7B OPENS
1.4B
1.4B OPENS (MANUAL)
1.5C CLOSES
1.6C CLOSES
1.4C
1.4C CLOSES (MANUAL)
1.5D OPENS
1.6D OPENS
PLUG SUIT IN
1.5D CLOSES
1.6D CLOSES
1.7D OPENS
1.4D
1.5C OPENS
1.6C OPENS
PLUG SUIT IN
1.5B CLOSES
1.6B CLOSES
1.4B
1.4B CLOSES (MANUAL)
1.5C CLOSES
1.6C CLOSES
1.7C OPENS
1.4C
1.4C OPENS (MANUAL)
1.5D OPENS
1.6D OPENS
PLUG SUIT IN
1.5D CLOSES
1.6D CLOSES
1.7D OPENS
1.4D
1.4D OPENS (MANUAL)
1.6B OPENS
PLUG SUIT IN
1.4B OPENS (MANUAL)
1.4B
1.4B OPENS (MANUAL)
1.5C OPENS
1.6C OPENS
PLUG SUIT IN
1.5C CLOSES
1.6C CLOSES
1.7C OPENS
1.4C
1.4C OPENS (MANUAL)
1.5D OPENS
1.6D OPENS
PLUG SUIT IN
1.5D CLOSES
1.6D CLOSES
1.7D OPENS
1.4D
1.4D OPENS (MANUAL)

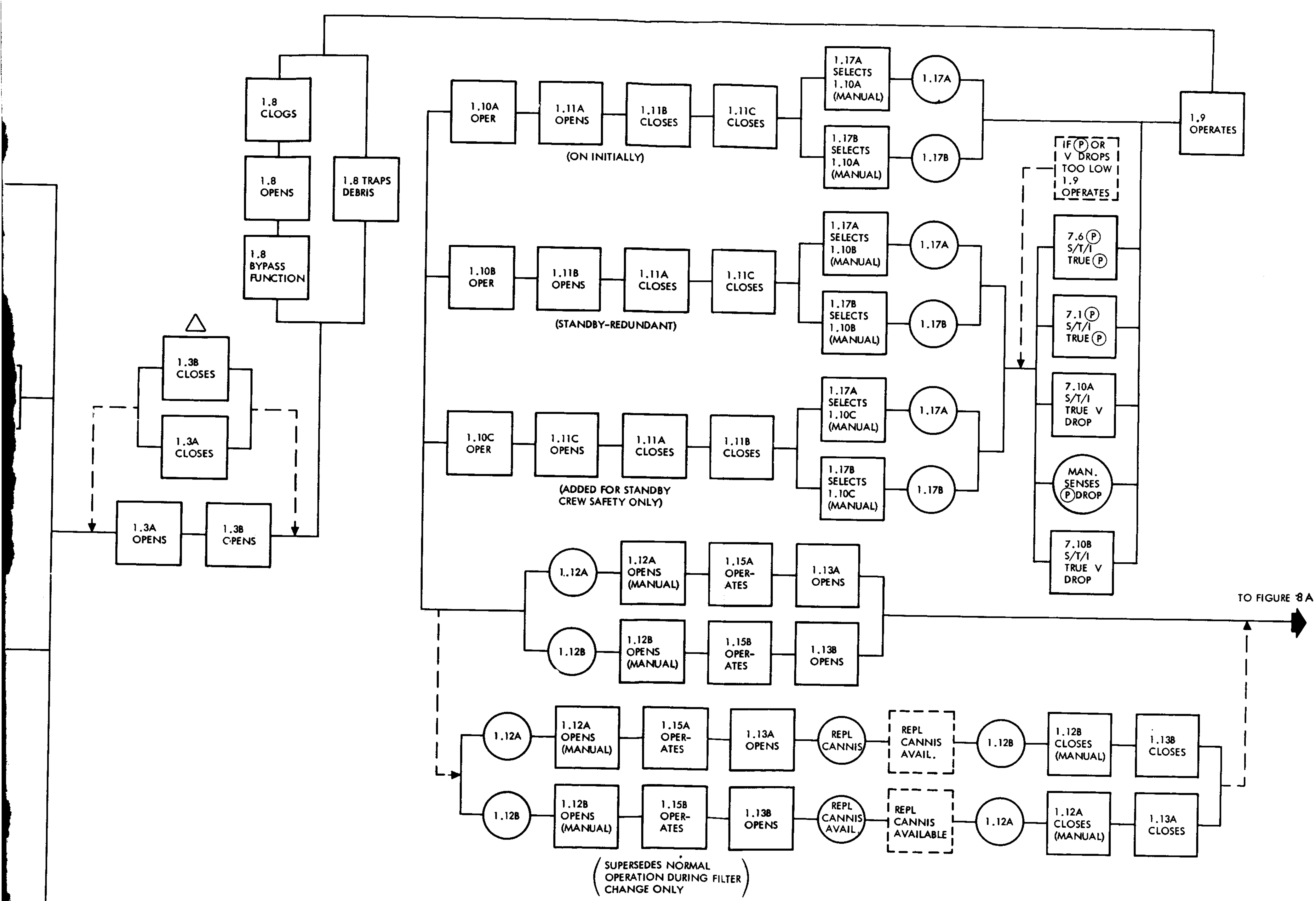

Figure 8. Suit/Cabin Air Circuit Logic Diagram

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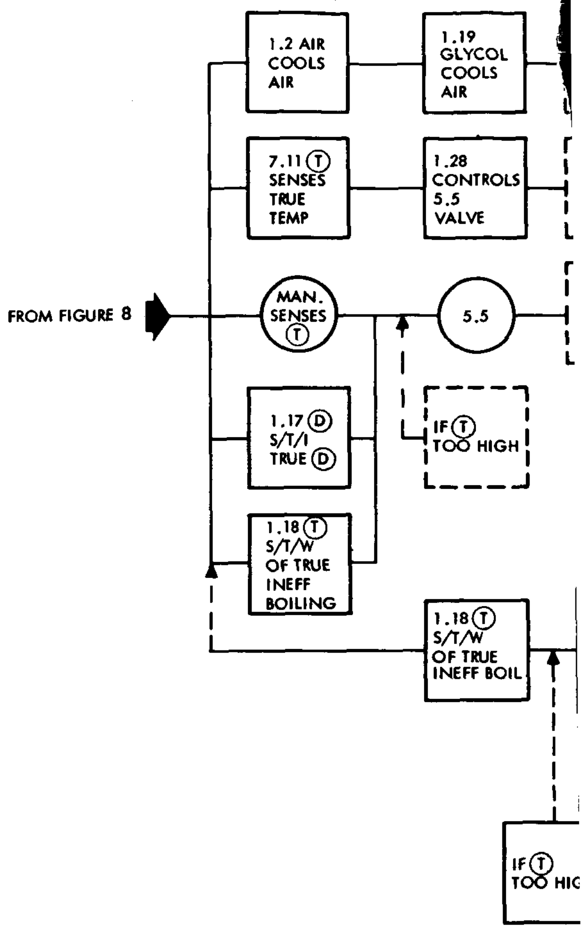
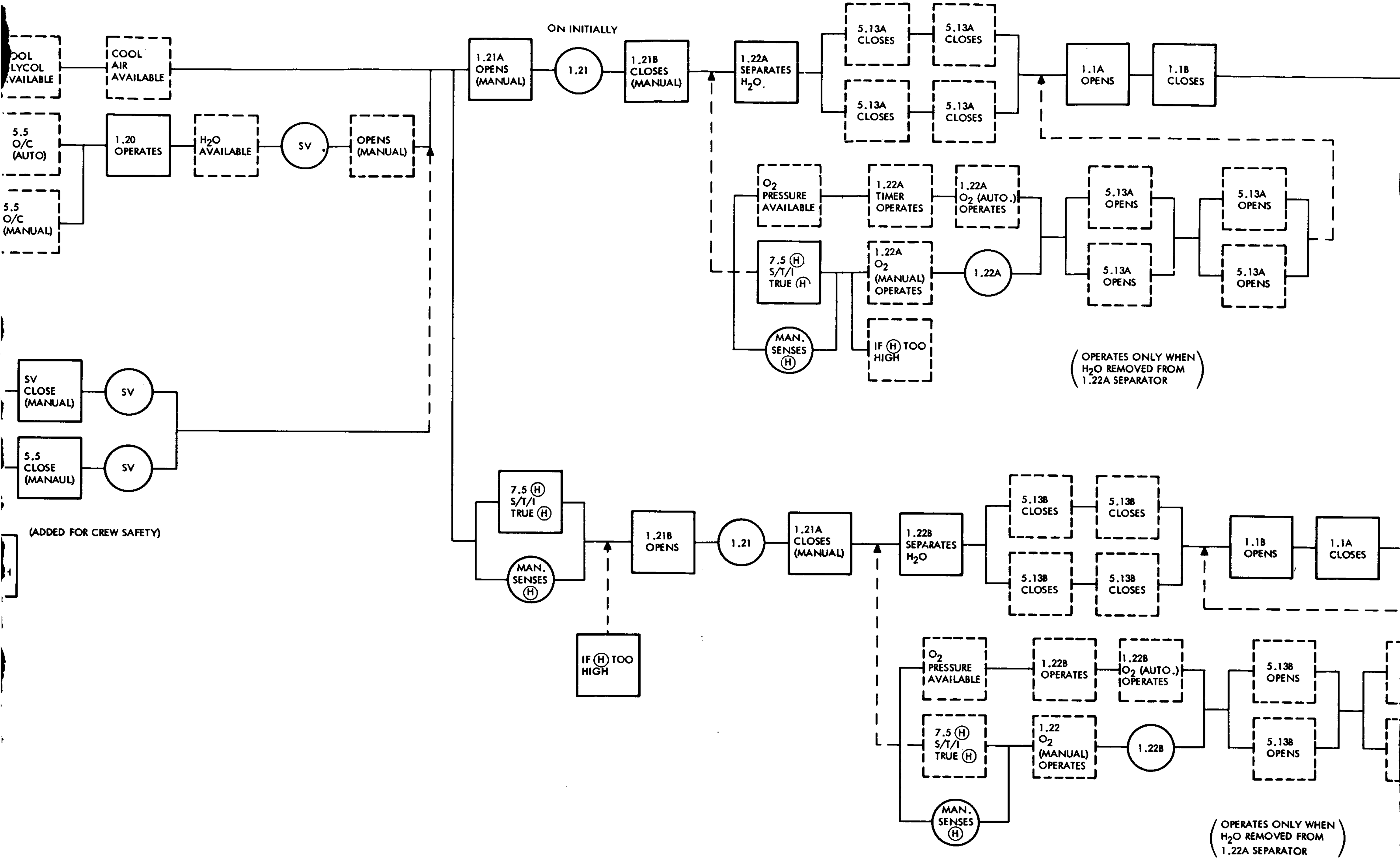
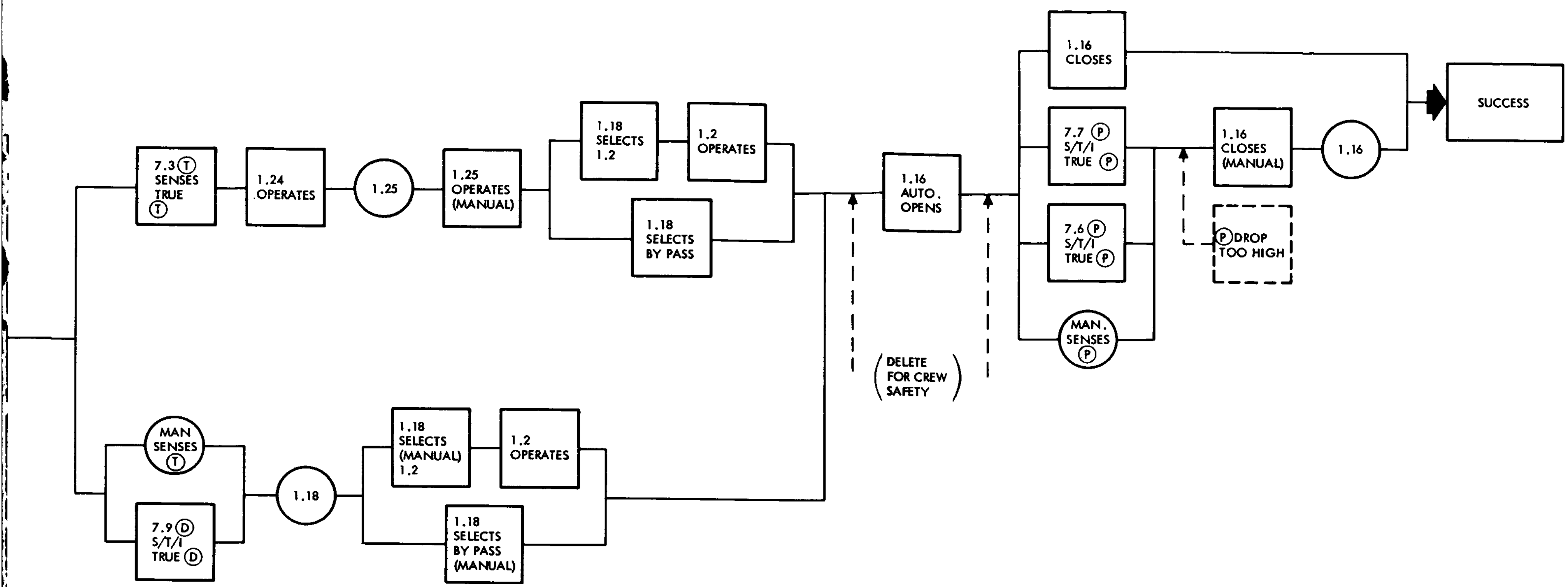
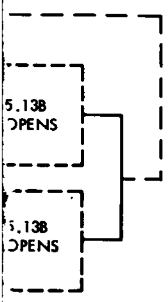

1.2 AIR COOLS AIR
1.19 GLYCOL COOLS AIR
7.11 T SENSES TRUE TEMP
1.28 CONTROLS 5.5 VALVE
FROM FIGURE 8
MAN. SENSES T
5.5
IF T TOO HIGH
1.17 D S/T/I TRUE D
1.18 T S/T/W OF TRUE INEFF BOILING
1.18 T S/T/W OF TRUE INEFF BOIL
IF T TOO HIG


OOL LYCOL AVAILABLE
COOL AIR AVAILABLE
5.5 O/C (AUTO)
5.5 O/C (MANUAL)
1.20 OPERATES
H2O AVAILABLE
SV
OPENS (MANUAL)
ON INITIALLY
1.21A OPENS (MANUAL)
1.21
1.21B CLOSES (MANUAL)
1.22A SEPARATES H2O
5.13A CLOSES
1.1A OPENS
1.1B CLOSES
O2 PRESSURE AVAILABLE
1.22A TIMER OPERATES
1.22A O2 (AUTO.) OPERATES
5.13A OPENS
7.5 H S/T/I TRUE H
1.22A O2 (MANUAL) OPERATES
1.22A
MAN. SENSES H
IF H TOO HIGH
OPERATES ONLY WHEN H2O REMOVED FROM 1.22A SEPARATOR
SV CLOSE (MANUAL)
5.5 CLOSE (MANAUL)
(ADDED FOR CREW SAFETY)
1.21B OPENS
1.21A CLOSES (MANUAL)
1.22B SEPARATES H2O
5.13B CLOSES
1.1B OPENS
1.1A CLOSES
1.22B OPERATES
1.22B O2 (AUTO.) OPERATES
5.13B OPENS
1.22 O2 (MANUAL) OPERATES
1.22B

2





COMPONENT NUMBER	ITEM DESCRIPTION
1.1	Valve, check, raspberry, normally closed
1.2	Heat exchanger, air-air regeneration cross-flow
1.3	Valve, check, dual, butterfly, normally closed
1.4	Valve, limiting and manual shutoff, normally open
1.5	Connector, normally open
1.6	Valve, check, flapper, normally closed
1.7	Connector, orifice, normally closed
1.8	Debris trap, screen filter
1.9	Catalytic filter
1.10	Compressor, centrifugal, 10,000 rpm
1.11	Valve, check, raspberry, normally closed
1.12	Valve, manual shutoff, normally open
1.13	Valve, check raspberry, normally closed
1.15	CO_2 and odor adsorber
1.16	Valve, pressure relief with manual override, normally closed
1.17	Switch, rotary, four-position assembly
1.18	Valve, electrically actuated control with manual override
1.19	Heat exchanger, glycol-air cross-flow
1.20	Heat exchanger, water-air cross-flow
1.21	Valve, diverter, manual
1.22	Water separator, with shutoff valve and actuator
1.24	Temperature control, magnetic amplifier
1.25	Temperature selector, rheostat
1.28	Temperature control, magnetic amplifier
5.5	Valve, electrically actuated control with manual override
5.13	Valve, check, quadruple assembly, normally open
7.1	Sensor, air pressure
7.3	Sensor, air temperature
7.6	Sensor, pressure differential
7.7	Sensor, pressure differential
7.9	Sensor, air temperature
7.10	Sensor, voltage indication
7.11	Sensor, air temperature

LEGEND

- △ = CABIN EMERGENCY/SUIT MODE
- ○ = HUMAN OPERATION
- □ = MECHANICAL OPERATION
- S/T/I = SENSES, TRANSMITS, AND INDICATES
- S/T/W = SENSES, TRANSMITS, AND WARNS
- (D) = POSITION
- (P) = PRESSURE
- (T) = TEMPERATURE
- (V) = VOLTAGE
- SV = SERVO VALVE
- O/C = OPEN OR CLOSED

NOTE:
A, B, C, ETC, AFTER COMPONENT NUMBER INDICATES POSITION IN CIRCUIT OF SUCCESSIVE IDENTICAL COMPONENT

Notes:
Does not include ground check-out provisions.
Unless otherwise indicated parallel redundancy is assumed rather than sequential redundancy.
Normal operation and normal conditions assumed unless otherwise indicated.
Logic based upon requirements for success.

Figure 8a. Suit/Cabin Air Circuit Logic Diagram

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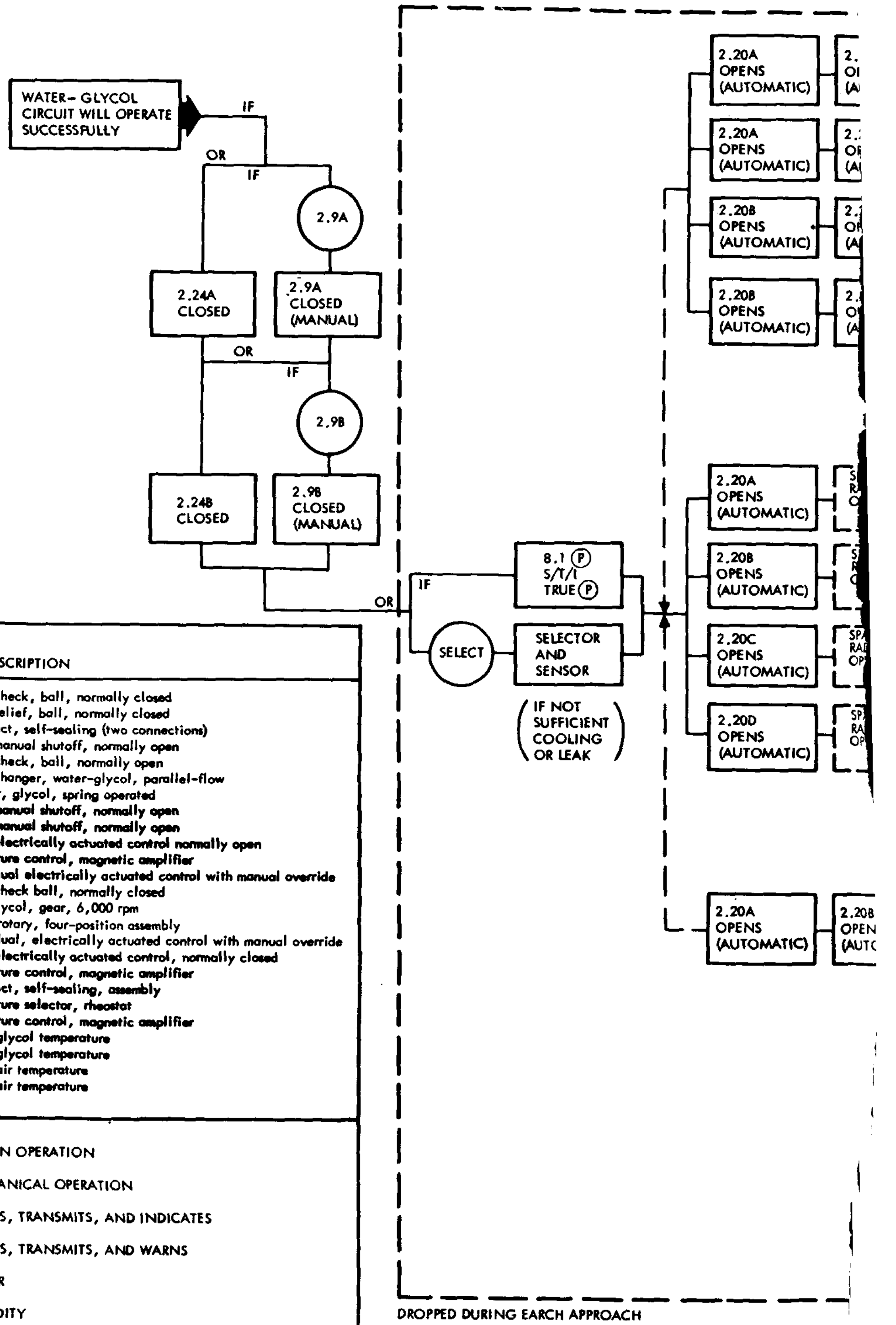


COMPONENT NUMBER	ITEM DESCRIPTION
2.1	Valve, check, ball, normally closed
2.2	Valve, relief, ball, normally closed
2.3	Disconnect, self-sealing (two connections)
2.4	Valve, manual shutoff, normally open
2.5	Valve, check, ball, normally open
2.6	Heat exchanger, water-glycol, parallel-flow
2.7	Reservoir, glycol, spring operated
2.8	Valve, manual shutoff, normally open
2.9	Valve, manual shutoff, normally open
2.10	Valve, electrically actuated control normally open
2.12	Temperature control, magnetic amplifier
2.13	Valve, dual electrically actuated control with manual override
2.14	Valve, check ball, normally closed
2.15	Pump, glycol, gear, 6,000 rpm
2.16	Switch, rotary, four-position assembly
2.19/5.6	Valve, dual, electrically actuated control with manual override
2.20	Valve, electrically actuated control, normally closed
2.22	Temperature control, magnetic amplifier
2.24	Disconnect, self-sealing, assembly
3.5	Temperature selector, rheostat
3.7	Temperature control, magnetic amplifier
8.6	Sensor, glycol temperature
8.9	Sensor, glycol temperature
9.5	Sensor, air temperature
9.6	Sensor, air temperature

○ = HUMAN OPERATION

□ = MECHANICAL OPERATION

S/T/I = SENSES, TRANSMITS, AND INDICATES

S/T/W = SENSES, TRANSMITS, AND WARNS

(E) = POWER

(H) = HUMIDITY

O/C = OPEN OR CLOSED

NOTE:
A, B, C, ETC., AFTER COMPONENT NUMBER INDICATES POSITION IN CIRCUIT OF SUCCESSIVE IDENTICAL COMPONENT

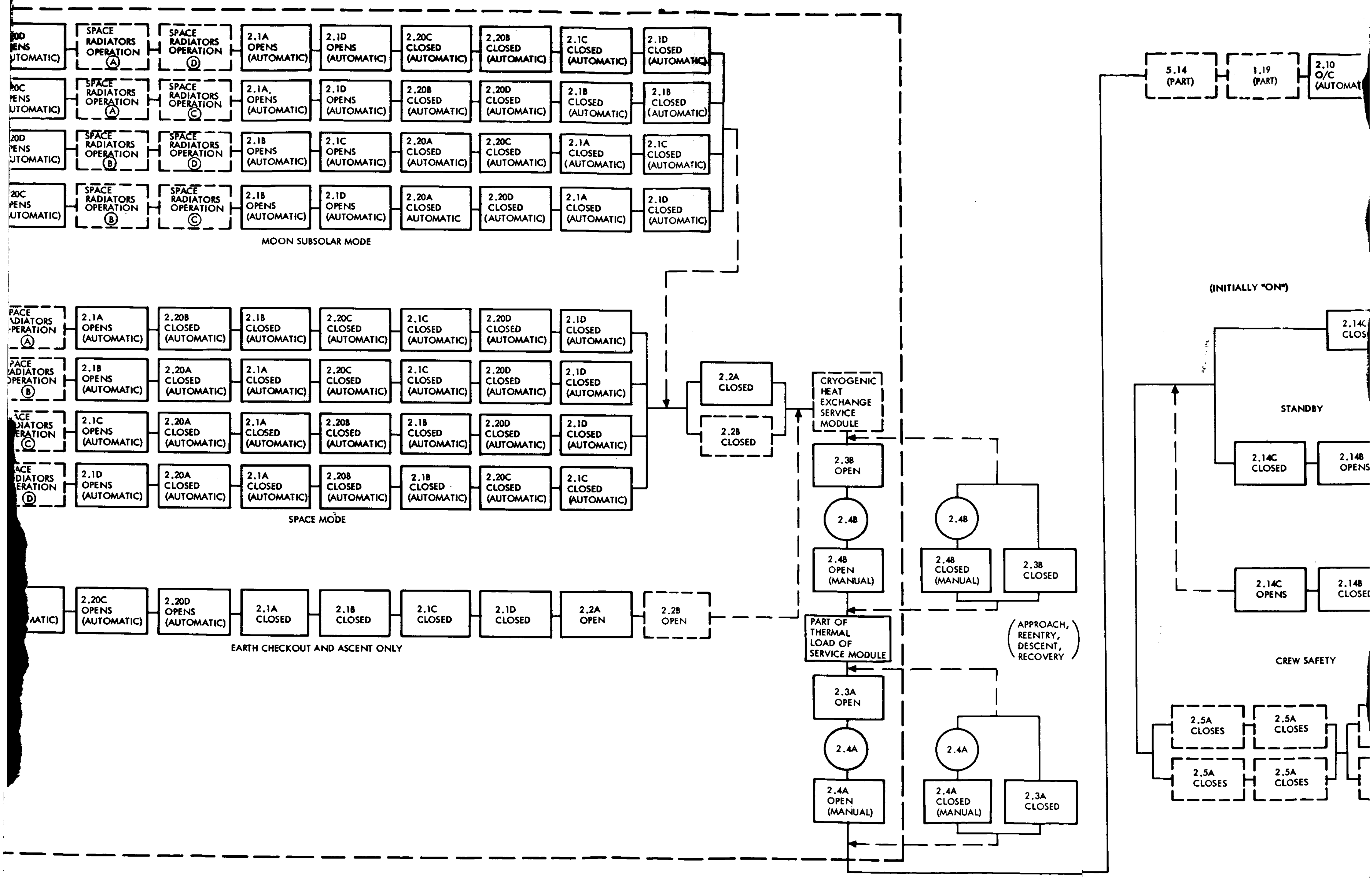


Figure 14. Apollo Water-Glycol Circuit-Reliability Analysis

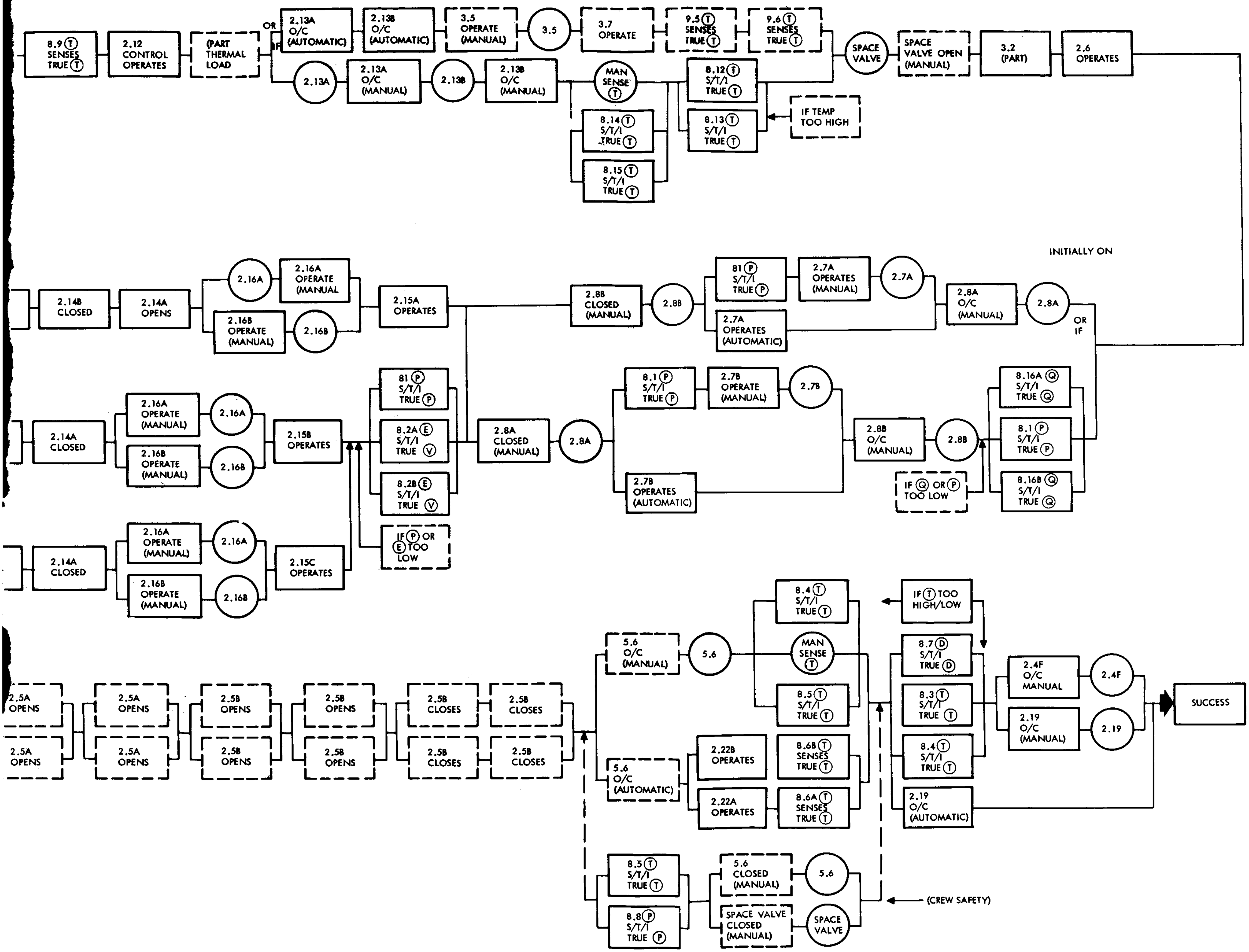
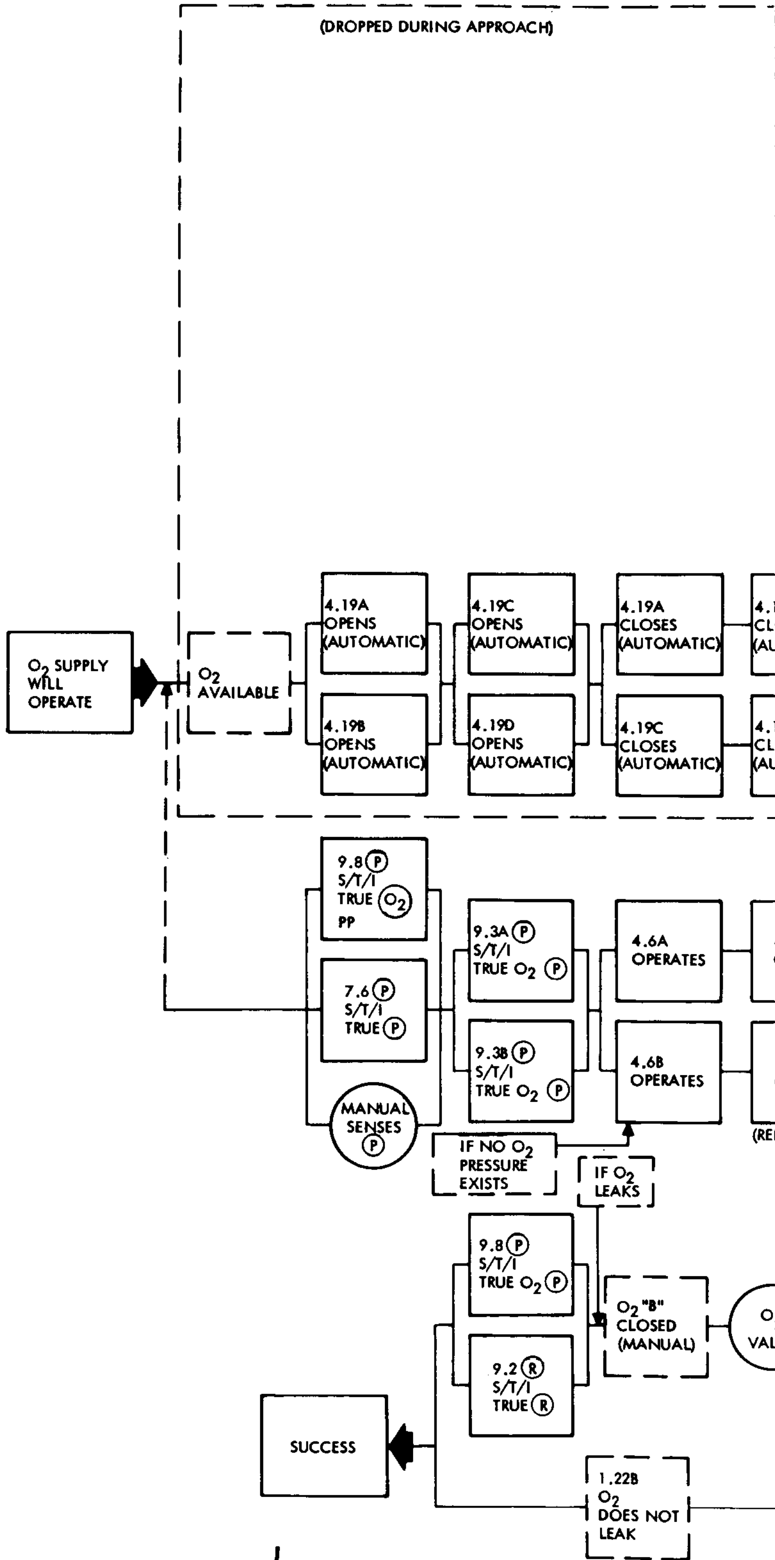
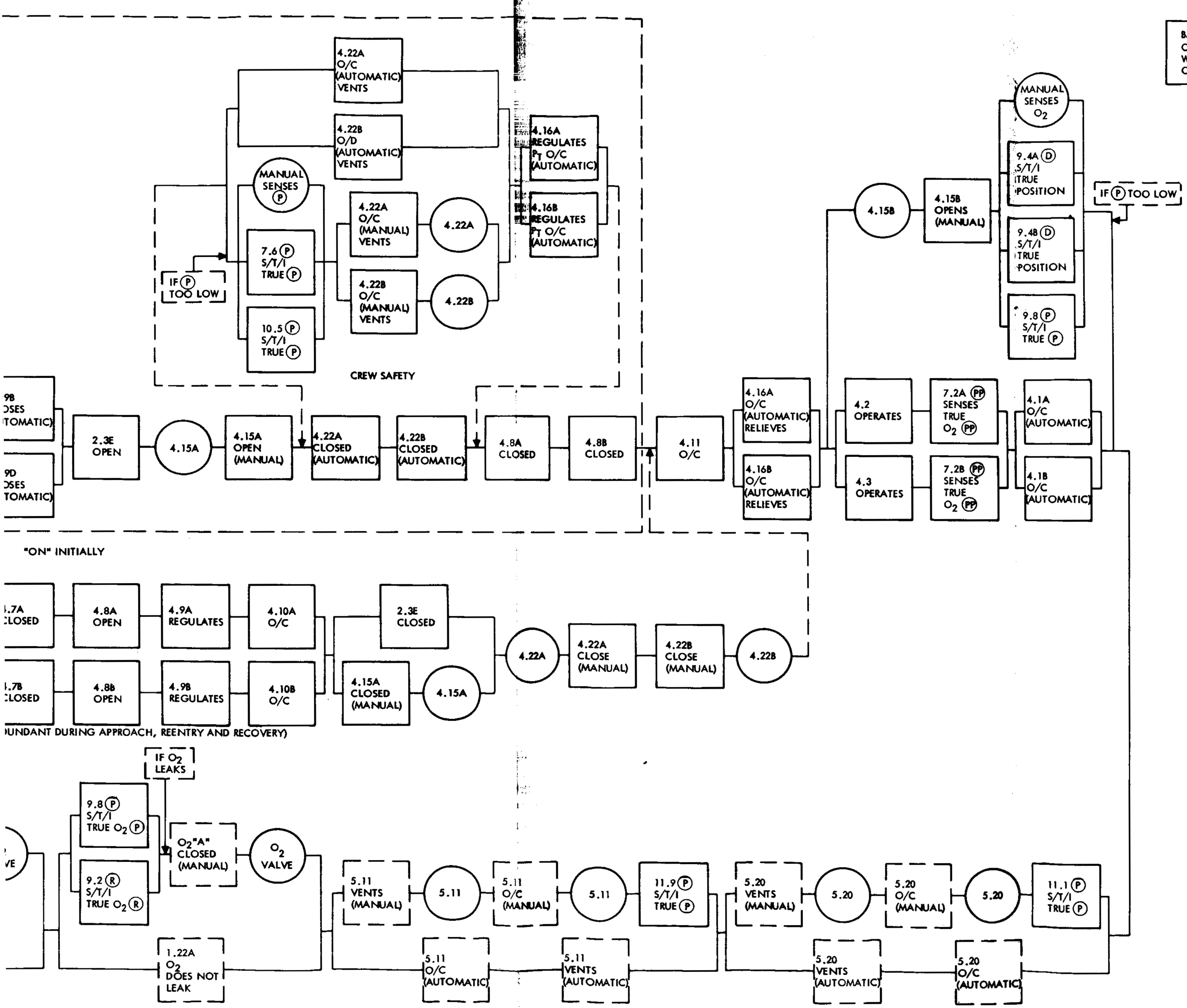
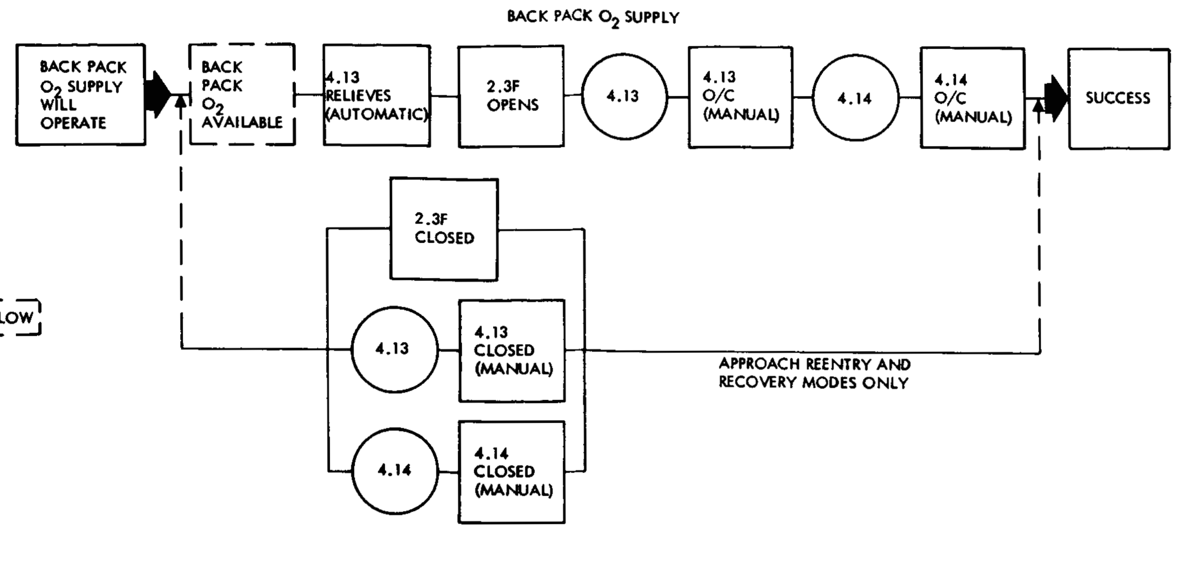


Figure 9. Water-Glycol Circuit Logic Diagram

[redacted]NTIAL







COMPONENT NUMBER	ITEM DESCRIPTION
1.22	Water Separator, with shutoff valve and actuator
2.3	Disconnect, self-sealing (one connection)
4.1	Valve, electrically actuated control, dual assembly
4.2	Pressure control, magnetic amplifier assembly
4.6	Tank, oxygen storage, 7,500 psi
4.7	Valve, manual shutoff, high pressure, normally closed
4.8	Valve, manual shutoff, high pressure, normally closed
4.9	Valve, regulator, high pressure, normally closed
4.10	Valve, check ball, normally open
4.11	Valve, relief, ball, normally closed
4.13	Valve, relief and manual shutoff, normally closed
4.14	Cap, sealing
4.15	Valve, manual shutoff, normally closed
4.16	Valve, demand pressure and relief, normally open
4.17	Valve, manual shutoff, normally closed
4.19	Valve, regulator, quadruple assembly
4.22	Valve, regulator (dual) manual override
5.11	Valve, regulator and relief, manual override
5.20	Valve, regulator and relief, manual override
7.2	Sensor, O_2 partial pressure
7.6	Sensor, pressure differential
9.2	Sensor, O_2 flow rate
9.3	Sensor, O_2 pressure (entry)
9.4	Sensor, position
9.8	Sensor, O_2 pressure
10.5	Sensor, command module total pressure

○ = HUMAN OPERATION
□ = MECHANICAL OPERATION
(PP) = PARTIAL PRESSURE
(P_T) = TOTAL PRESSURE
(R) = FLOW RATE
S/T/I = SENSES, TRANSMITS, AND INDICATES
S/T/W = SENSES, TRANSMITS, AND WARNS

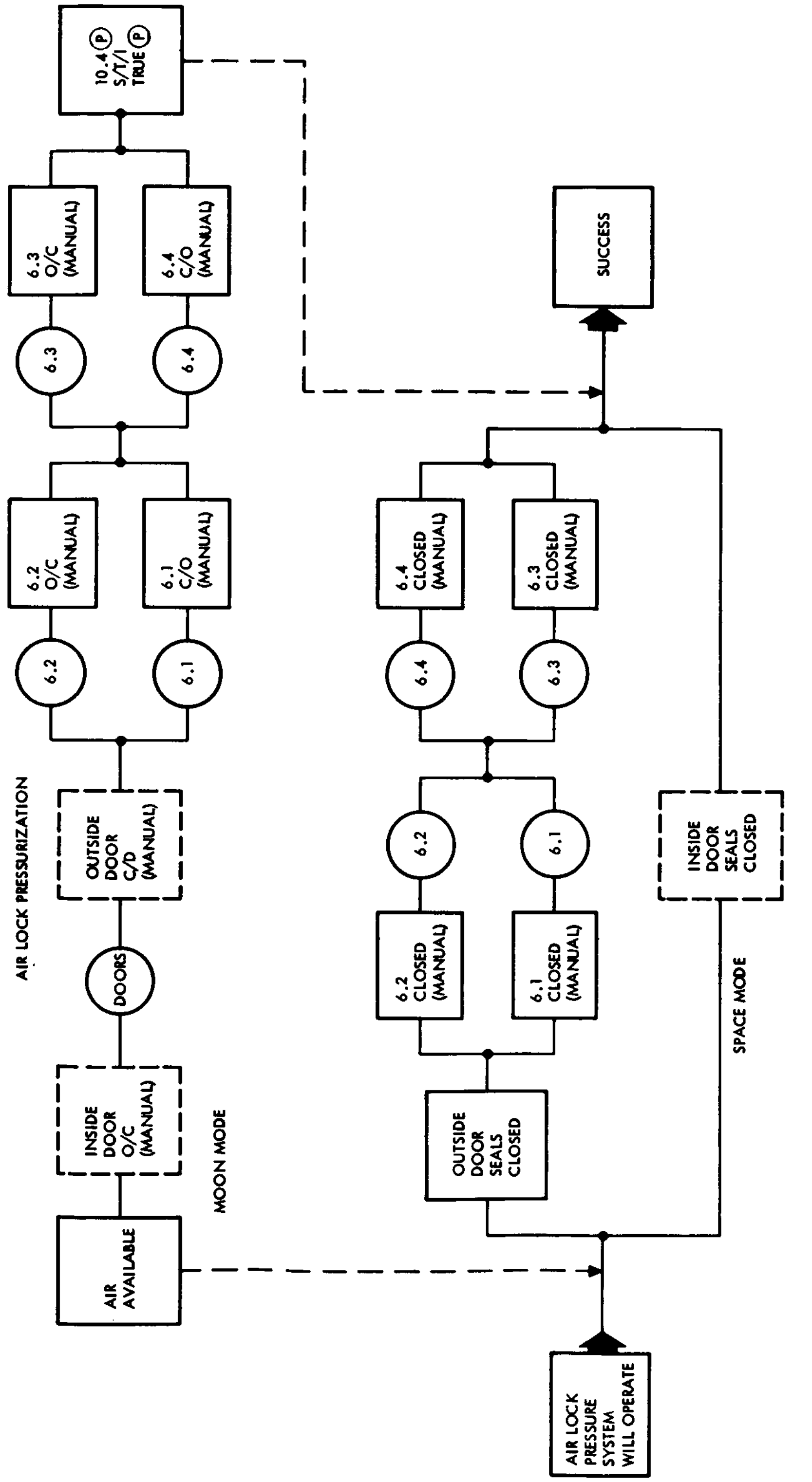
NOTE:
A, B, C, ETC., AFTER COMPONENT NUMBER INDICATES POSITION IN CIRCUIT OF SUCCESSIVE IDENTICAL COMPONENT

Figure 10. Oxygen Supply Circuits Logic Diagram

2

[redacted]

[redacted]



COMPONENT NUMBER	ITEM DESCRIPTION	
6.1	Valve, shutoff, manual	○ = HUMAN OPERATION
6.2	Valve, shutoff, manual	□ = MECHANICAL OPERATION
6.3	Valve, shutoff, manual	S/T/I = SENSES, TRANSMITS, AND INDICATES
6.4	Valve, shutoff, manual	S/T/W = SENSES, TRANSMITS, AND WARNS
10.4	Sensor, airlock pressure	NOTE: A, B, C, ETC., AFTER COMPONENT NUMBER INDICATES POSITION IN CIRCUIT OF SUCCESSIVE IDENTICAL COMPONENT.

Figure 11. Air Lock Pressurization Circuit Logic Diagram

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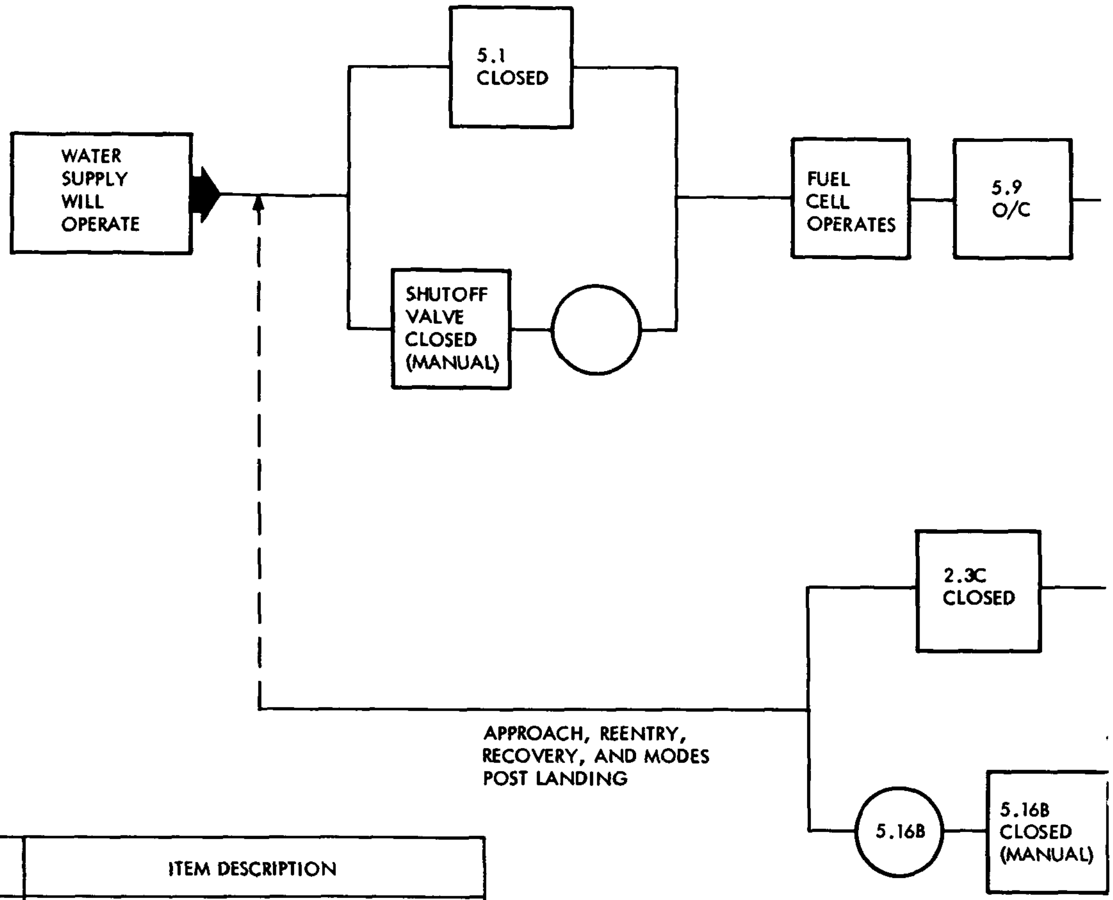
WATER SUPPLY SYSTEM



COMPONENT NUMBER	ITEM DESCRIPTION
2.3	Disconnect, self-sealing, (one connection)
5.1	Disconnect, self-sealing, normally closed
5.2	Valve, check, preset, normally closed
5.3	Valve, shutoff, manual, normally closed
5.4	Valve, three-way, manual, normally open
5.8	Valve, shutoff, manual, normally closed
5.9	Valve, check, ball, normally closed
5.10	Water tank, bladder
5.14	Heat exchanger, glycol-water parallel flow
5.15	Water tank, bladder
5.16	Valve, three-way, manual, normally open
5.17	Valve, shutoff, manual, normally closed
11.2	Sensor, water quantity

○ = HUMAN OPERATION

□ = MECHANICAL OPERATION

S/T/I = SENSES, TRANSMITS, AND INDICATES

S/T/W = SENSES, TRANSMITS, AND WARNS

Ⓠ = QUANTITY

NOTE:
A, B, C, ETC., AFTER COMPONENT NUMBER INDICATES POSITION IN CIRCUIT OF SUCCESSIVE IDENTICAL COMPONENT

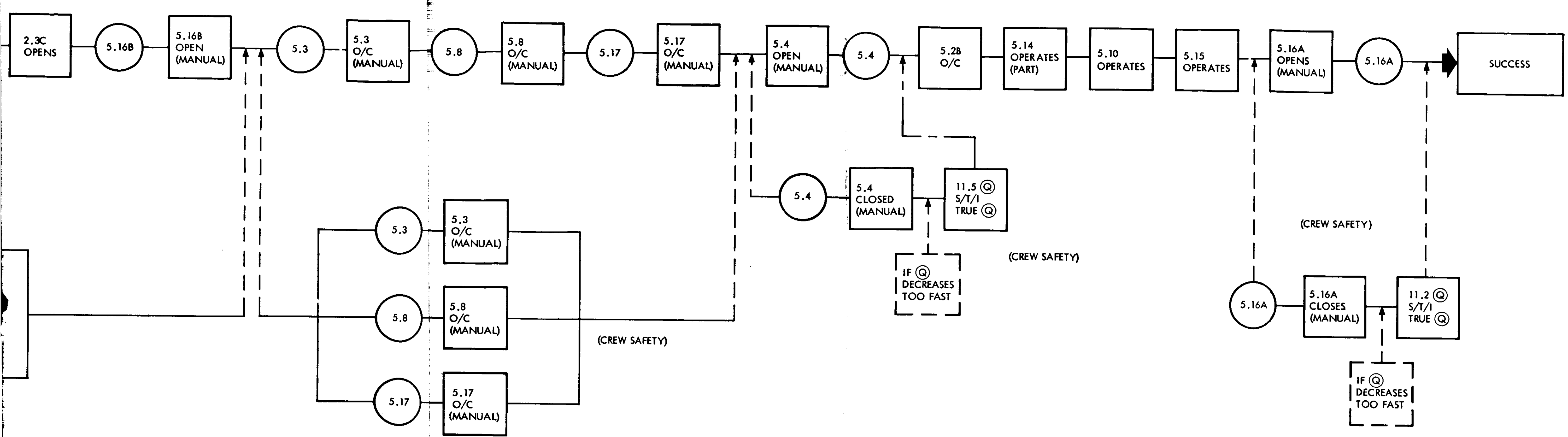


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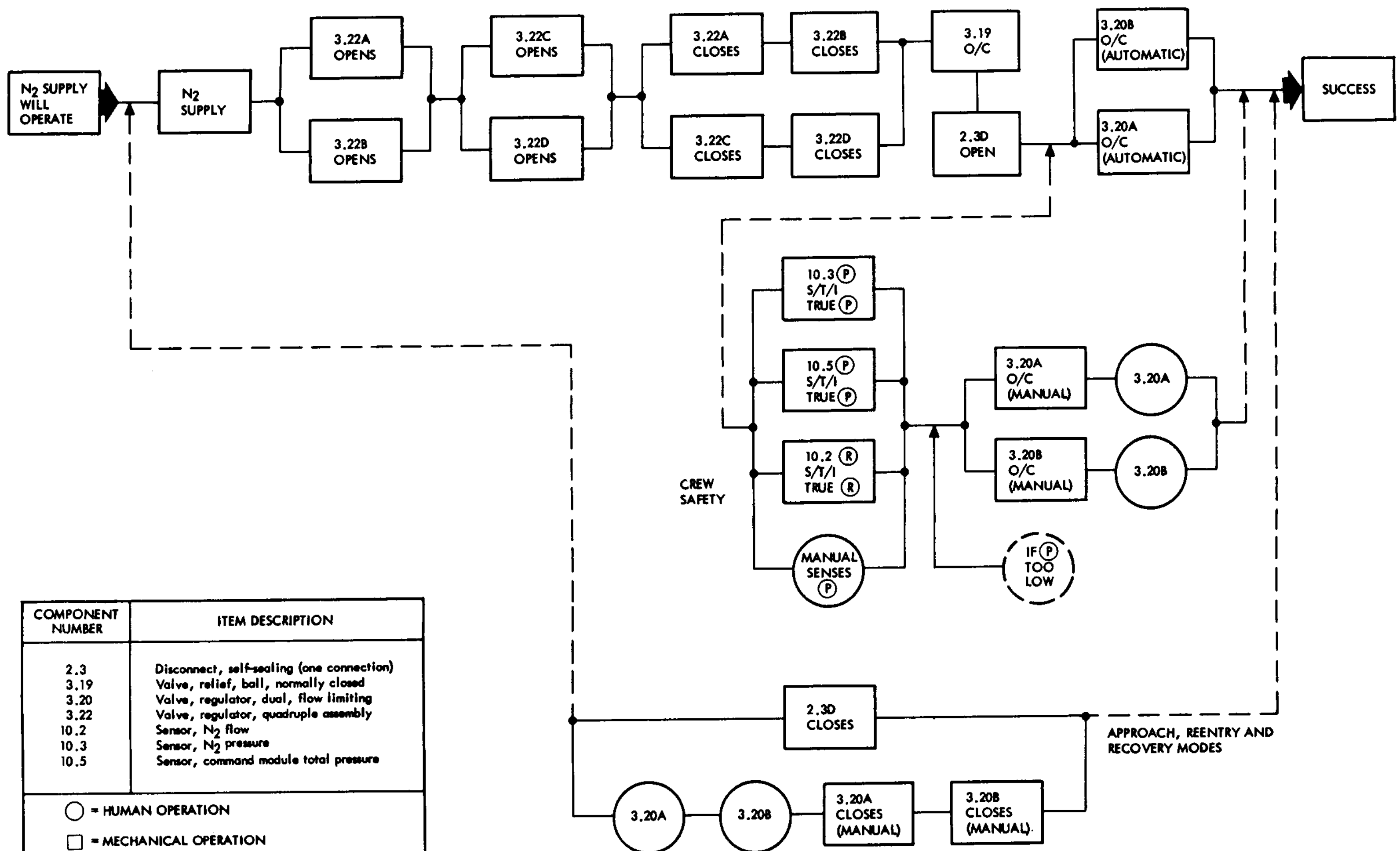
Figure 12. Water Supply Circuit Logic Diagram

[redacted]

[redacted]



COMPONENT NUMBER	ITEM DESCRIPTION
2.3	Disconnect, self-sealing (one connection)
3.19	Valve, relief, ball, normally closed
3.20	Valve, regulator, dual, flow limiting
3.22	Valve, regulator, quadruple assembly
10.2	Sensor, N_2 flow
10.3	Sensor, N_2 pressure
10.5	Sensor, command module total pressure

○ = HUMAN OPERATION

□ = MECHANICAL OPERATION

S/T/I = SENSES, TRANSMITS, AND INDICATES

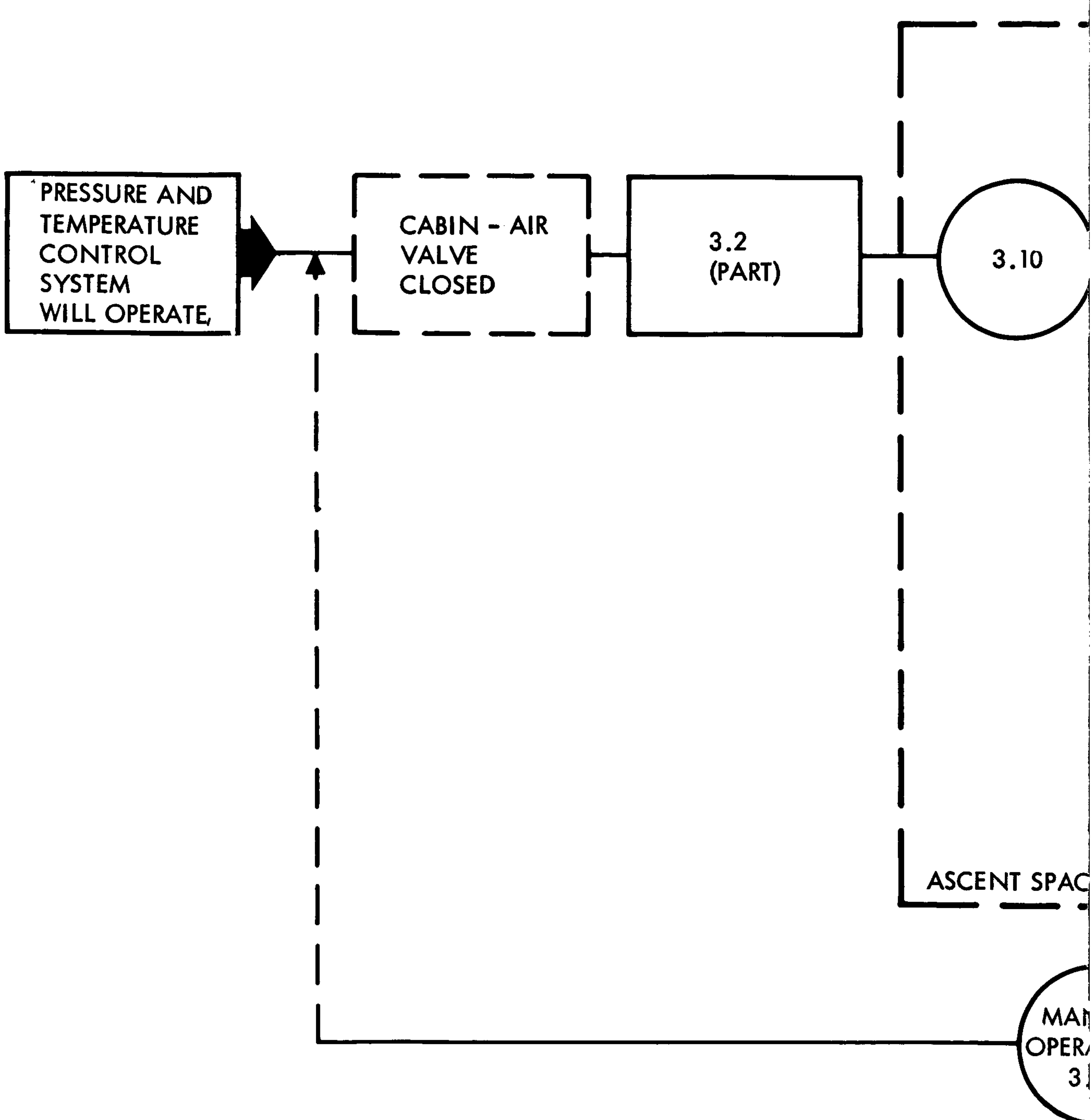
S/T/W = SENSES, TRANSMITS, AND WARNS

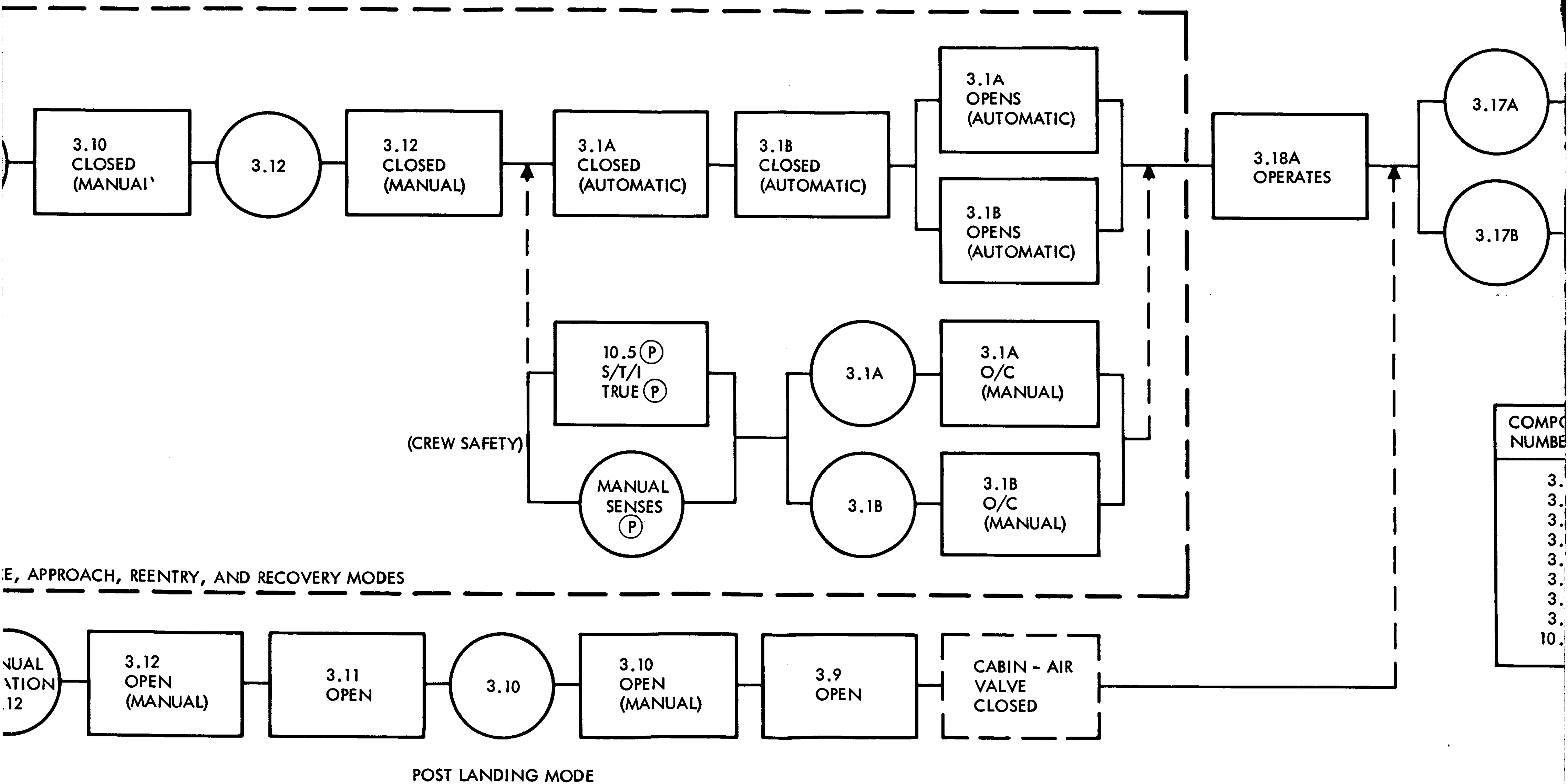
Ⓡ = FLOW RATE

NOTE:
A, B, C, ETC., AFTER COMPONENT NUMBER INDICATES POSITION IN CIRCUIT OF SUCCESSIVE IDENTICAL COMPONENT.

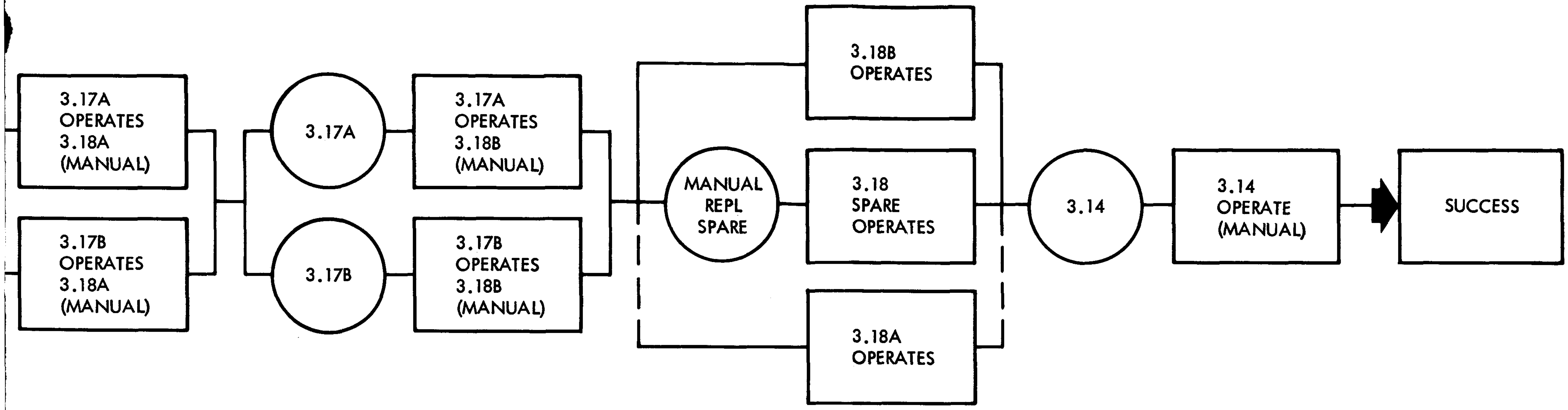
Figure 13. Nitrogen Supply Circuit Logic Diagram

[redacted]


PRESSURE AND TEMPERATURE CONTROL SYSTEM WILL OPERATE,
CABIN - AIR VALVE CLOSED
3.2 (PART)
3.10
ASCENT SPAC
MAN OPERA 3


3.10
CLOSED
(MANUAL)
3.12
3.12
CLOSED
(MANUAL)
3.1A
CLOSED
(AUTOMATIC)
3.1B
CLOSED
(AUTOMATIC)
3.1A
OPENS
(AUTOMATIC)
3.1B
OPENS
(AUTOMATIC)
3.18A
OPERATES
3.17A
3.17B
10.5 P
S/T/I
TRUE P
(CREW SAFETY)
MANUAL
SENSES
P
3.1A
3.1A
O/C
(MANUAL)
3.1B
3.1B
O/C
(MANUAL)
COMP
NUMBE
3.
3.
3.
3.
3.
3.
3.
3.
10.
E, APPROACH, REENTRY, AND RECOVERY MODES
NUAL
ATION
.12
3.12
OPEN
(MANUAL)
3.11
OPEN
3.10
3.10
OPEN
(MANUAL)
3.9
OPEN
CABIN - AIR
VALVE
CLOSED
POST LANDING MODE

2



POST LANDING MODE

ONENT R	ITEM DESCRIPTION
1	Valve, dual regulator and relief, with manual override
2	Heat exchanger, air-glycol cross-flow
9	Snorkel, inflow and outflow (required to operate post-landing only)
10	Valve, manual shutoff, normally closed
12	Valve, manual shutoff, normally closed
14	Valve, diverter, manual.
17	Switch, rotary, three-position, assembly
18	Blower, fan, 6,000 rpm
5	Sensor, command module total pressure

○ = HUMAN OPERATION

□ = MECHANICAL OPERATION

S/T/I = SENSES, TRANSMITS, AND INDICATES

S/T/W = SENSES, TRANSMITS, AND WARNS

Ⓠ = QUANTITY

NOTE: A, B, C, ETC., AFTER COMPONENT NUMBER INDICATES POSITION IN CIRCUIT OF SUCCESSIVE IDENTICAL COMPONENT

Figure 14. Command Module Pressure/Temperature Control System Logic Diagram

[redacted]

[redacted]

Table 13. Reliability Apportionment of GSE Water - Glycol Unit

Item Description	Quantity	Complexity	Failure Rate Percent λ Thousand	Equivalent MTBF (hrs)	Equivalent Cycles	Assumed Usage Cy/Hrs.
N_2 Circuit						
Disconnect, Quick	1	10	2.86	34,950	1455	1/24
Valve, Manual, Shut-off	2	5	1.43	70,000		
Regulator, Pressure	1	10	2.86	34,950		
Valve, Manual, Bleed	1	5	1.43	70,000		
Valve, Vent, Relief	1	10	2.86	34,950		
Diaphragm	1	25	7.15	14,000		
Water - Glycol Circuit						
Disconnect, Quick	6	10	2.86	34,950		
Sensors, Temp.	4	5	1.43	70,000		
Sensors, Pressure	2	20	5.72	17,500		
Gages, Mech., Pressure	3	20	5.72	17,500		
Gages, Mech., Temp.	1	20	5.72	17,500		
Transducers, Temp. & Press.	4	30	8.58	11,700		
Controller, Temp. & Press.	2	40	11.44	8,720		
Valves, Flow & Press, Control	2	40	11.44	8,720		
Valves, Manual Shut-Off	8	5	1.43	70,000		
Valves, Solenoid	7	10	2.86	34,950		
Meter, Flow	1	30	8.58	11,700		
Pump, Vacuum	1	40	11.44	8,720		
Indicator, Micron	1	30	8.58	11,700		
Heaters	2	1	0.29	345,000		
Controls, Heater	2	2	0.57	175,000		
Exchanger, Heat	1	1	0.29	345,000		
Unit, Refrigeration	1	250	71.50	1,400		
Valve, Spring Loaded, Relief	2	10	2.86	34,950		
Valve, Check	2	5	1.43	70,000		
Pump, Turbine	1	15	4.29	23,300		
Switch, Pressure	1	15	4.29	23,300		
Motor, Pump	1	15	4.29	23,300		
Indicator, Liquid Level, Mech.	1	1	0.29	345,000		
Switch, Toggle	7	1	0.29	345,000	465,000	32/24
Lamp	7	1	0.29	345,000		
Valve, Flange	40	1	0.29	345,000		
Instrument, Tee	11	1	0.29	345,000		
Joints, Welded	100	-				
Reservoir	1	1	0.29	345,000		
Valve, Fill	1	5	1.43	70,000		

[redacted]

minimum values which must be obtained in order to meet an overall 300-hour MTBF requirement.

Failure rates are additive and, accordingly, trade-offs can be introduced in a simple manner. Should any component-apportioned value be outside of practical achievement, this value may be lowered and "traded-off" with other component values to arrive at the same cumulative total. Also, if parts can be obtained that are generally better than the apportioned reliabilitv figures, the reliability of the GSE mission essential equipment (GSEMEE) for a 50-hour mission time may be greatly improved. Considering the system checkout console and the water-glycol unit as comprising the GSEMEE and each just meeting a 300-hour MTBF, the reliability of the GSEMEE for a 50-hour maintenance-free mission time is 0.74082, that is, the probability of the GSEMEE failing during a 50-hour mission is 0.25918.

The analysis contains the quantities of each component and the relative complexity values. The equivalent cycles are based upon assumed frequencies which are also shown. The analysis is divided into an N_2 circuit and a Water-Glycol circuit for ease of use.

ELECTRICAL POWER SUBSYSTEM

Fuel Cell Module

Reliability analysis of the fuel cell subsystem during the period April through June 1962 has been oriented towards reapportioning the fuel cell module failure mode analysis and defining a qualification-reliability test plan. First-order failure modes that have a deleterious effect on module operation have been noted and design action have been taken to eliminate or minimize all first-order failure modes.

The reliability objective for the individual fuel cell module has been changed from 0.868 to 0.971 to be consistent with the Apollo mission requirements.

Reliability Reapportionment

During the last quarter a numerical reliability analysis was performed on the fuel cell subsystem, including its instrumentation. The results of this analysis proved to be incompatible with overall system reliability requirements, and following design improvements a new analysis will be made. The following paragraphs indicate the status of this activity to date, and the procedural steps taken to accomplish the apportionment of the system reliability requirement.

[redacted]

Component Operating Characteristics Study

Component operating characteristics were studied to determine their effect on mission reliability. Based on this study, components were classified as operational for the full duration of the mission or operational for short finite durations. A 400-hour mission time was used for components required to operate continuously throughout the mission. For components required to operate at intervals during the mission, the time was adjusted accordingly.

Component Ranking. All components were ranked and assigned relative reliability indicies expressed in terms of relative failure rates.

Failure Rate Study. Failure rate data from various sources were evaluated and compared to the relative failure rates assigned to all components by the ranking method. Adjustments were made where necessary. The failure-rate data sources used are cited in References 1, 2, 4, 6, and 10. The failure rates exhibited under a known set of environmental conditions were adjusted to the operating stresses to which the components will be subjected.

Logic Diagrams

A reliability logic diagram was prepared for the system as an arrangement of major blocks (Figure 15) in order to show the effect of a failure on the system operation. Each major block is an arrangement of components as shown in Figures 16 and 17.

Numerical Reliability Analysis

This analysis is intended to provide a basis for the apportionment of the system reliability requirements to establish independent module and component reliability objectives and to aid in selecting the best system and component designs by appraising the relative effects of different components, the redundancy of the parts, and other factors contributing to reliability.

Reliability Objectives

The reliability objective for the complete fuel cell subsystem is 0.9977 for a 400-hour mission. The reliability objective for the independent module was estimated to be 0.868 for the same mission. The reliability objective for individual modules was based on a subsystem which provides normal power when two or more modules are operating and emergency power when two modules fail. This reliability objective was further apportioned to establish component reliability objectives.

[redacted]

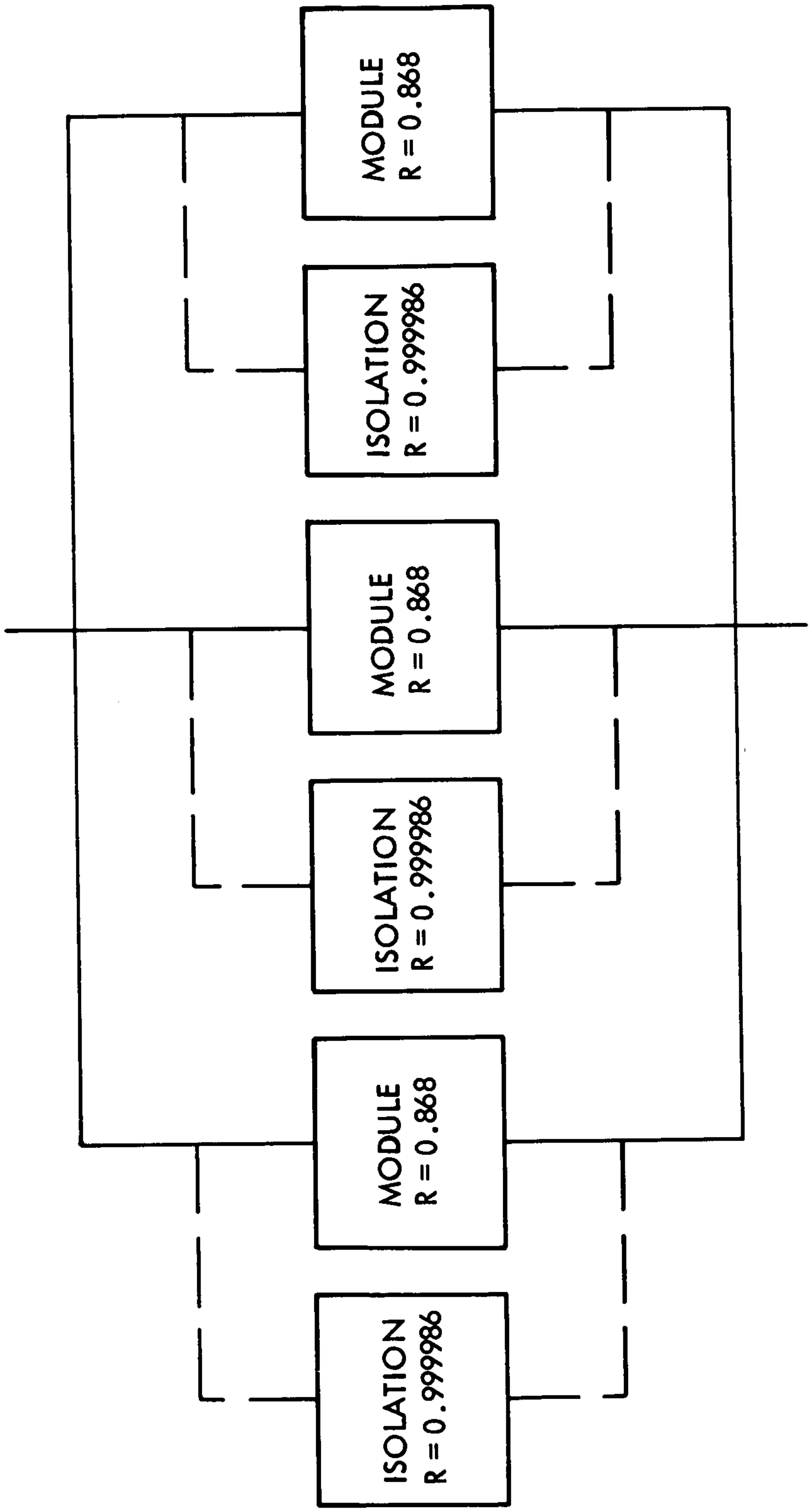


Figure 15. Fuel Cell Subsystem Simplified Reliability Logic Diagram

[redacted]

MODULE RELIABILITY = 0.868

MODULE	R = 0.9547
N_2 REGULATOR	R = 0.9973
O_2 REGULATOR	R = 0.9828
H_2 REGULATOR	R = 0.9835
MOTOR - PUMP-SEPARATOR-VALVE ASSEMBLY	R = 0.9865
MOTOR - PUMP-ASSEMBLY-GLYCOL	R = 0.9916
REGENERATOR BY-PASS-H_2	R = 0.9960
ACCUMULATOR	R = 0.9968
REGENERATOR BY-PASS VALVE-GLYCOL	R = 0.9978
REGENERATOR - H_2	R = 0.9988
REGENERATOR - GLYCOL	R = 0.9988
CONDENSER	R = 0.9988
2 PREHEATERS	R = 0.99940
TUBING AND MECHANICAL CONNECTIONS	R = 0.99940
WIRING AND ELECTRICAL TERMINALS	R = 0.99952
3 SHOCK MOUNTS	R = 0.99958
N_2 TANK	R = 0.99960
INSTRUMENTATION	R = 0.99968
MODULE JACKET	R = 0.99986
2 POROUS PLUGS	R = 0.999920
2 PURGE VALVES	R = 0.999980
PRESSURE RELIEF VALVE	R = 0.9999948
FILL VALVE - N_2 TANK	R = 0.9999972

Figure 16. Fuel Cell Module Assembly Simplified Reliability Logic Diagram

ISOLATION GROUP RELIABILITY = 0.999986

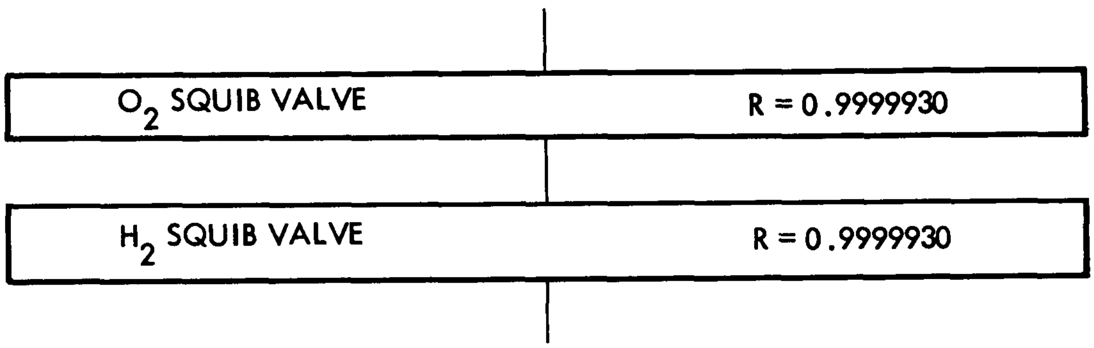


Figure 17. Fuel Cell Module Simplified Reliability Logic Diagram

[redacted]

Review of Objectives

The component reliability objectives were reviewed whenever a design change was made, or whenever failure rate data became available. New goals were established as required, and their effect on the remaining components of the independent module was analyzed. To date, three major reviews have been performed.

Monte Carlo Analysis

To demonstrate the physical meaning of the component failure rates and random failures associated with the subsystem operation during a 400-hour mission, the Monte Carlo method was applied to simulate operation on flights to the moon and return. The mathematical model provided mission realism through random determination of failures by simulating 70 complete flights. In case of a failure, the model indicated which component failed, the time of failure, the flight on which it occurred, and the status of system-power output as the result of the component failure.

Failure-Mode Analysis

A failure mode analysis, considering each component of an individual fuel cell module, has been completed during the reporting period. The failure mode analysis (Table 14) considers the component, failure modes of the component, probable cause of each failure, the effect of the failure on mission success and on crew safety, and a remarks column showing possible corrective action to preclude a failure. All first-order failures are deleterious to the individual module in which the failure occurs. There are no propagating or sequential failures that will cause a loss of the entire fuel cell subsystem.

Design Improvements

As a result of reliability considerations and design reviews the following design improvements have been incorporated into the fuel cell subsystem:

1. Secondary regenerative by-pass valve - improved porting by providing a more thermally efficient contact area of fluid (hydrogen) with the thermostat.

2. Nitrogen tank - improved circumferential weld area for ease of installation and inspection.

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Table 14. Fuel Cell Module Failure—Mode Analysis

Component	Failure Mode	Cause	Effect On: Mission Success	Effect On: Crew Safety	Remarks
Secondary Regulator Valve by-pass	Loss of temp. control; leak	Out of Calibration, vibration	One - Module failure - none Two - Module failure - none Three - Module failure - loss	One - Module failure - none Two - Module failure - none Three - Module failure - loss	
Water discharge valve	Stop water flow; Leak H_2; H_2 in Water tank	Fatigue per-set of seals	One - Module failure - Two - Module failure - Three - Module failure -	One - Module failure - none Two - Module failure - none Three - Module failure - loss	Use of upstream check valve will preclude failure.
H_2 & O_2 purge valves	Leak, will not open	Vibration, creep	No effect	No effect	Addition of normally open solenoid valve downstream will preclude module failure should purge valve fail to close.
N_2 tank	Loss of N_2	Stress, rupture, fatigue	One - Module failure - none Two - Module failure - loss Three - Module failure - loss	One - Module failure - none Two - Module failure - none Three - Module failure - loss	Low stress conditions and good quality control in welding methods is necessary.
N_2 regulator	High pressure; none exists; low pressure; none exists	Fatigue, bending, or failure of pressure indicator	One - Module failure - none Two - Module failure - loss Three - Module failure - loss	One - Module failure - none Two - Module failure - none Three - Module failure - loss	Incorporation of rupture disk upstream will prevent module jacket rupture.
O_2 & H_2 regulators	High pressure; none exists; low pressure; none exists; leakage	Fatigue, bending, or failure of pressure indicator	One - Module failure - none Two - Module failure - loss Three - Module failure - loss	One - Module failure - none Two - Module failure - none Three - Module failure - loss	Redundancy of bellows, proper material selection, and reduction of stress should preclude leakage.
Condenser	Leak	Fatigue	One - Module failure - none	One - Module failure - none	Material selection important. Welded or brazed joints should be low-stressed.

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[redacted]

Table 14. Fuel Cell Module Failure—Mode Analysis (Cont'd)

Component	Failure Mode	Cause	Effect On: Mission Success	Effect On: Crew Safety	Remarks
Primary regenerator	Leak; loss of control	Fatigue, shear	One - Module failure - none	One - Module failure - none	Material selection important. Welded or brazed joints should be low-stressed.
Secondary loop regenerator	Leak; temperature tolerance not maintained; no temperature control	Fatigue, shear	One - Module failure - none	One - Module failure - none	Material selection important. Welded or brazed joints should be low-stressed.
Pump and separator assembly	Leak H_2; stop pumping; H_2 & H_2O	Shear, loss of lube perset of seals	One - Module failure - none Two - Module failure - loss Three - Module failure - loss	One - Module failure - none Two - Module failure - none Three - Module failure - loss	Conservative stress, good quality control and material selection necessary; leakage prevented by using hermetic seals.
Fluid pump motor 105 cycles	Leak; stop pumping	Shear, loss of lube perset of seals	One - Module failure - none Two - Module failure - loss Three - Module failure - loss	One - Module failure - none Two - Module failure - none Three - Module failure - loss	Conservative stress, good quality control and material selection necessary; leaking prevented by using hermetic seals.
Module jacket	Loss of N_2	Stress rupture	One - Module failure - none Two - Module failure - loss Three - Module failure - loss	One - Module failure - none Two - Module failure - none Three - Module failure - loss	Addition of blow-plug or press-valve vented overboard will increase mission success and crew survival.
Circulating fluid pump assembly	Pump stops; leak	Shear, loss of lube, seals fail	One - Module failure - none Two - Module failure - loss Three - Module failure - loss	One - Module failure - none Two - Module failure - none Three - Module failure - loss	Failure will require shutdown of module.
Secondary fluid pump motor, 400 cycles	Pump stops; leak	Shear, loss of lube, seals fail	One - Module failure - none Two - Module failure - loss Three - Module failure - loss	One- Module failure - none Two - Module failure - none Three - Module failure - fail	Failure will require shutdown of module.

[redacted]

Table 14. Fuel Cell Module Failure—Mode Analysis (Cont'd)

Component	Failure Mode	Cause	Effect On: Mission Success	Effect On: Crew Safety	Remarks
Torsion rod assembly	Leak KOH	Torsion, shear, tension, bending			Quality control very important.
Fuel cell element	Power output reduced, loss of KOH or reactants	Oxidation, brittle, failure	One - Module failure - none Two - Module failure - loss Three - Module failure - loss	One - Module failure - none Two - Module failure - none Three - Module failure - loss	Use of high factor of safety, and selection of approved materials will reduce failure possibility.
Module heaters	Short	Vibration, rubbing	No effect	No effect	Failure will be indicated prior to launch.
Heater harness	Short	Vibration	No effect	No effect	Failure will be indicated prior to launch.
Segmented manifold (module)	Loss of O_2 and H_2	Shear, fatigue	One - Module failure - none Two - Module failure - loss Three - Module failure - loss	One - Module failure - none Two - Module failure - none Three - Module failure - loss	Relocate squib on reactant manifold to prevent loss of all reactants.
Pre-heaters (reactants)	Loss of reactants or glycol	Fatigue	One - Module failure - none Two - Module failure - loss Three - Module failure - loss	One - Module failure - none Two - Module failure - none Three - Module failure - loss	Elimination of as many weld or braze areas as possible will increase reliability.
Accumulator glycol	Leak N_2 to glycol, loss	Fatigue, stress, rupture	One - Module failure - none Two - Module failure - loss Three - Module failure - loss	One - Module failure - none Two - Module failure - none Three - Module failure - loss	Redundant bellows will preclude failure.
Pump and condenser assembly manifolds	Leak H_2 and H_2O glycol leak	Shear	One - Module failure - none Two - Module failure - loss Three - Module failure - loss	One - Module failure- none Two - Module failure - none Three - Module failure - loss	Connections which require braze or weld should be kept to minimum.

[redacted]ENTIAL

Table 14. Fuel Cell Module Failure—Mode Analysis (Cont'd)

Component	Failure Mode	Cause	Effect On		Remarks
			Mission Success	Crew Safety	
Assembly of fuel cell module	Leak reactants, leak N_2 to atmosphere	Vibration, fatigue			
H_2 and H_2O pump differential transducer	Electrical connections or mechanical connections fail loss or H_2	Fatigue, stress, rupture			
Glycol differential pressure transducer	Leak glycol, electrical or mechanical connection failure				
H_2 and O_2 porous plug differential pressure transducer	Low reading, high reading, no pressure indication, leak reactant	Fatigue	One - Module failure - none Two - Module failure - loss Three - Module failure - loss	One - Module failure - none Two - Module failure - none Three - Module failure - loss	Failure to indicate pressure does not constitute failure.
O_2, N_2 and H_2 downstream absolute pressure transducer	Low reading, high reading, no pressure indication, leak reactant	Fatigue			
O_2 and H_2 upstream absolute pressure transducer	Low reading, high reading, no pressure indication, leak reactants	Fatigue			Low or no pressure indication will not cause module shutdown.
O_2 and H_2 porous plug	No flow, no indication, leak reactants	Contaminant, fatigue			No reading does not constitute failure - pilot can check pressure through redundancy.

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Table 14. Fuel Cell Module Failure—Mode Analysis (Cont'd)

Component	Failure Mode	Cause	Effect on: Mission Success	Effect on: Crew Safety	Remarks
Primary and secondary pump magnetic speed pick-up	Leak H_2O, H_2, or glycol	Fatigue, vibration			Hermetic seals of H_2 pump, placed on separator side to minimize H_2 leakage.
Surface temperature sensor instrumentation	False or no reading	Fatigue	No effect	No effect	Redundant; pilot can check.
Immersion temperature sensor instrumentation	Leak H_2 or O_2, false or no reading	Fatigue shear			Redundant; pilot can check; low or no indication does not cause failure.
Reference pressure primary regulator assembly	Leak H_2 into N_2	Vibration, fatigue	One - Module failure - none Two - Module failure - loss Three - Module failure - loss	One - Module failure - none Two - Module failure - none Three - Module failure - loss	Design to reduce plumbing stresses as much as possible.
Porous plug housing	False or no reading, leak H_2 or O_2	Shear, fatigue	One - Module failure - none Two - Module failure - loss Three - Module failure - loss	One - Module failure - none Two - Module failure - none Three - Module failure - loss	Any failure resulting in false reading does not constitute module failure; reactant leaks will cause module shutdown.
Bi-metal regenerator bypass valve	No control leakage	Seizing, brinelling			Careful inspection of surface finish, low stress

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[redacted]

3. Regenerator by-pass valve (bi-metallic) - added brazing of locknut to prevent any possibility of it vibrating loose; increased brazing area around tube connection to distribute stress.

4. Glycol accumulator - changed mounting to provide greater resistance to vibration and shock.

5. Condenser - increased brazing area around tube connections to distribute stress, redesigned header connections and tubing to give greater strength and simplify brazing.

6. Water discharge valve - eliminated one set of bellows to prevent hydrogen from leaking into potable water; redesigned assembly to facilitate checking of valve-pressure setting, and improved hydrogen and water inlet.

7. Pressure regulator mounts - eliminated material which showed sublimination problems in space vacuum.

8. Segmented manifold - proposed alternate design to reduce stressing of components, eliminate sealing problem, simplify manufacturing and assembly, and reduce human error.

9. Circulation pump and separator - changed porting of hydrogen and water inlet to reduce turbulence and slugging of water and added labyrinth seal to prevent water accumulating in pockets; performed design-information test to evaluate vane material relative to wear properties, evaluate bearings relative to capacity and sealing, and test material compatability; improved manufacturing and assembly procedure of motor rotor and stator to allow checking of rotor-to-stator clearance.

10. Glycol coolant pump - initiated design information test of compatible materials relative to graphite bearings reacting with the stainless steel shafting (carbon in the graphite bearings can react with the chrome in the stainless steel in the presence of water under stagnant conditions and cause pit corrosion).

11. Torsion rod system - increased beam strength of linkage beam and simplified the forging process to produce this part, reduced friction at contact and pivot points of linkage system, and simplified assembly by making rods symmetrical so they can be assembled either way, reducing human error; insulated piping of primary regenerator to prevent any shorting of electrodes due to vibration and shock during launch.

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12. Module jacket - eliminated brazed joint between insulation screen and liner to eliminate any contamination due to flux.

13. Secondary loop regenerator - increased brazing area around tube connections to distribute the stress, and designed header connections and tubing to give greater strength and simplify brazing.

14. Heater harness - initiated study of design of a built-in fuse as a fail-safe device in event of a short.

15. Intermediate mount bracket - recommended machining procedure to minimize human error, and alerted quality control for further study.

16. Control cluster assembly - eliminated prestressing of tubing joints, redesigned piping subassembly to simplify brazing to allow for systematic checking of all joints for leaks, thereby decreasing the possibility of human error, located component piping to prevent interaction during vibration and shock, specified close quality control of all assembly and testing procedures, and simplified assembly of components to allow accessibility for replacement during all phases of testing.

17. Instrumentation - utilized redundancy and fail-safe techniques to maximize crew safety.

18. Mechanical connections - performed design-information tests on welding and brazing techniques to establish rigid quality control procedures to insure achievement of all performance requirements.

Test Procedure Format

A test-procedure outline intended to ensure a uniform format for test procedures was prepared in accordance with SID 62-332[1], SID 62-204[2], Mil-T-9107[3], and Mil-T-18303[4], and plans were begun for the use of standard tests in module testing.

One standard test will consist of a predetermined power-demand cycle using high loads and changes of load to cause above-normal stresses on parts. The demand cycle will be designed particularly to reduce those stresses which were the causes of failure in the component failure-mode

1 - Reference 2
2 - Reference 9
3 - Reference 8
4 - Reference 10

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analysis. The intent is to cause failures in a short time and thus to establish safety factors for the critical modes.

Additional standard tests for environmental conditions have been studied in which the environments will be varied through normal and above-normal levels. In this search for critical weakness the intent is to cause failures in a short time with a limited sample and thus to establish the safety factors for environmental failures.

Developmental Testing

Subscale Single Cells

A multivariate program has been prepared to investigate the following characteristics of 5-inch electrodes:

Electrode reproducibility in terms of measurable physical properties, performance and endurance.

Relationship between measurable physical properties and performance and endurance characteristics.

Correlation between the measurable physical properties of electrodes and the measurable physical properties of the excess corners obtained when the circular electrodes are cut from square plates.

A sample of approximately 40 sets of five-inch hydrogen and oxygen fuel-cell electrodes will be available for designed-experiment evaluations. Non-destructive inspection will be conducted on all electrodes and nine sets will be systematically selected for destructive inspection. The measurement of physical properties will be used to determine the within-unit, unit-to-unit, and time-to-time components of variance for each respective response. The responses to be measured will include mean pore size, nickel powder shape, open and total porosity, sinter thickness, permeability, bubble pressure, X-ray diffraction, and chemical content.

The remaining sets of electrodes that have not been used to obtain destructive inspection responses will be operated individually to obtain performance profiles. The electrodes will then be operated simultaneously at open-circuit conditions to determine the running-time-to-failure. The endurance tests will be conducted simultaneously in the same temperature oven to minimize the influence of experimental error on test results.

This program is just getting under way and will require approximately two months to complete.

Apollo-Size Single Cells

Manufacturing Process Investigation. A multiple-balance designed experiment has been prepared to determine the relationship between measurable physical properties and the performance-to-endurance characteristics of Apollo-size electrodes, and to evaluate the activation process variables for the oxygen electrode.

Two levels each of four measurable physical property variables will be investigated. These variables include the thickness of the fine pore, the percentage porosity of the fine pore, mean size of the coarse pore, and the percentage porosity of the coarse pore. The three activation process variables which will be studied simultaneously (at each of two levels) include oxidation time, oxidation temperature, and activation-solution concentration. A total of sixty-four electrodes will be available (four electrodes each of sixteen unique electrode configurations). These electrodes will be randomly assigned to the factor-level combinations of the activation process matrix.

It should be noted that this program in its present form is dependent on assumptions about the outcome of the subscale-single-cell program described above. In the event that unanticipated results occur, this program will be revised.

Apollo Operating Parameter Evaluation. A full-factorial designed experiment has been prepared to determine both the separate and combined effects of three operating variables on electrode performance to endurance. These variables and their respective levels include the pressure differential at two levels, the temperature at three levels, and percent electrolyte concentration at two levels. Each of the twelve factor-level combinations will be repeated four times and forty-eight electrodes will, therefore, be required. The particular electrode configuration to be used has been selected on the basis of current thought on the optimum characteristics required. At the conclusion of the manufacturing process investigation, which will be conducted concurrently with this experiment, a new combination of optimum characteristics may be determined. Should a significant improvement in electrode state-of-the-art be indicated, a follow-on performance parameter evaluation will be required.

Identification Procedures

During the past quarter criteria have been established to be used in determining the serialization of fuel cell parts and components. The criteria used to determine the mode of identification are as follows:

[redacted]

Serialization

The unit is a separate function identity, (control, regulator, single cell).

The part is subject to wear, (gears, pump vanes, bearings).

The part can cause a critical failure of the system.

The unit is a salable item, (single module or spares).

Heat Coding

The part is highly stressed and critical, (tierods).

The part is critical with sensitive manufacturing processes, (teflon seals, electrode sinters).

The specific units now considered for serialization are identified by an x in Table 15.

Table 15. Units Considered for Serialization

Part Name	Part Number	Data Plate	Serial No. Required	Heat Code Required
Complete powerplant assembly	600100	X		
Assembly of fuel cell element	600072		X	
Assembly of fuel elements	600069		X	
Assembly of oxidizer element	600066		X	
Fuel sinter material, fine	600053			X[1]
Fuel sinter material, coarse	600055			X[1]
Oxidizer sinter material, fine	600057			X[1]
Oxidizer sinter material, coarse	600058			X[1]

[redacted]

Table 15. Units Considered for Serialization (Cont)

Part Name	Part Number	Data Plate	Serial No. Required	Heat Code Required
Fuel cell gasket	600010			X[1]
Electrolyte	600060			X[1]
Fuel cell heating element	601246		X	
Fuel cell ceramic pigtail connector	601319		X	
Fuel cell resilient mount	600144, 145		X	
Assembly of water check valve	600137		X	
Water check diaphragm	600131			X
Assembly of primary circulation pump	601324		X	
Assembly of primary circulation pump rotor	601342		X	
Primary circulation pump vane	601343		X[1]	
Primary circulation pump bearing	601341		X	
Primary circulation pump motor stator and housing	601386		X	
Primary circulation pump motor rotor and sleeve	601387		X	
Primary circulation pump motor receptacle	601359		X	

[redacted]

Table 15. Units Considered for Serialization (Cont)

Part Name	Part Number	Data Plate	Serial No. Required	Heat Code Required
Primary circulation pump motor magnetic pickup	601385		X	
Primary regenerator	601247		X	
Assembly of primary regenerator by-pass valve	600186		X	
Primary regenerator by-pass valve bimetallic element	600147		X	
Secondary pump assembly	600215		X	
Secondary pump rotor assembly	600214		X	
Secondary pump stator assembly	600222		X	
Secondary pump gear driver	600212		X[1]	
Secondary pump gear idler	600213		X[1]	
Secondary pump front bearing	600203		X	
Secondary pump rear-drive bearing	600204		X[1]	
Secondary pump rear idler bearing	600205		X[1]	
Secondary pump rear bearing	600220		X	
Secondary pump receptacle assembly	600218		X	

[redacted]

Table 15. Units Considered for Serialization (Cont)

Part Name	Part Number	Data Plate	Serial No. Required	Heat Code Required
Secondary pump magnetic pickup			X	
Assembly of secondary regenerator	601459		X	
Secondary regenerator by-pass valve thermostat assembly	600962		X	
Secondary regenerator by-pass valve diaphragm	601457			X
Water discharge valve diaphragm			X	X
Solenoid valves			X	
EBW valves			X	
Relief valve			X	
Electrical connectors			X	
Pressure pickups			X	
Temperature pickups			X	
Teflon pipe packings				X[1]
Reactant pressure regulator assembly	600022		X	
Assembly of reactant pressure regulator bellows	600954		X	
Nitrogen regulator assembly	600073		X	

Table 15. Units Considered for Serialization (Cont)

Part Name	Part Number	Data Plate	Serial No. Required	Heat Code Required
Nitrogen regulator bellows assembly	600950		X	
Assembly of nitrogen tank	600138		X	
Nitrogen tank half	600139			X
Assembly of reactant preheaters	601233		X	
Assembly of module jacket	601400		X	
Lower pressure module jacket	601414		X	
Module insulation jacket	601448		X	
Tierod system torsion tierod assembly	600973		X	
Tierod system torsion rod	600969			X
Tierod system tie bolt	600970			X
Tierod system coupling nut	600971			X
Tierod system hub	600968			X
Tierod system bearing ring	600974		X	
Assembly of unit condenser	601213		X	
Assembly of glycol tank	600118		X	
Glycol bladder			X	

1 - Marking must be on packaging rather than on individual parts.

[redacted]

Electrical Distribution Subsystem

NASA and S&ID approval was obtained for the redundant dc and ac bus structures. Reliability analysis was emphasized in verifying the requirement for the structures and three static inverters, any one of which will provide the ac power requirements.

A further apportionment of components was made as shown in Table 16.

Table 16. Electrical Distribution Subsystem Reliability Apportionments

Item	Reliability
Supercritical gas storage fuel cell reactants	0.9989
Fuel cell subsystem	0.9977
Fuel cell module	0.971
DC distribution (2 buses)	0.9962
GSE umbilical connector	0.99999
Command module - service module connector	0.99995
Sequencer	0.99999
AC generation and distribution	0.99999
Single static inverter	0.9786
Entry batteries	0.99993
Battery charger (2 required)	0.995

Reliability evaluations of potential suppliers for static inverters and reentry batteries was completed.

Space Radiators

Two fuel cell space radiator configurations were studied to determine which would provide the higher reliability. The first configuration (Figure 18) consists of two radiators with a single coolant loop. The alternate configuration (Figure 19) consists of three radiators with redundant coolant loops.

[redacted]

Numerical Analysis

Standard failure rates from the Martin Handbook of Generic Failure Rates[1] were used for conducting the analysis.

The numberical analysis for both systems is as follows:

Component Values - 400-Hour Mission

Lines	R = 0.99998	= 0.05/million hours
Fittings	R = 0.99998	= 0.05/million hours
Valve	R = 0.99816	= 4.60/million hours

Probability of Failure in Radiator Loop Due to Meteroids

Total probability = 0.9999000

Probability per fuel cell loop = 0.9999875

Probability of Mission Success

Configuration 1 - 0.9999999549 , = .011275 failures/million hours

Configuration 2 = 0.9999999823 , = .004425 failures/million hours

The numerical analysis for probability of mission success shows a negligible difference in reliability, and both are significantly higher than the apportioned reliability requirement of 0.9998 for the radiator loop subsystem.

Other parameters such as weight and complexity were analyzed. The two-radiator, single-loop configuration was approximately 10 pounds lighter than the three-radiator, redundant-loop configuration; the smaller unit had six components compared to a total of 28 components for the larger one. The two-radiator, single-loop configuration is the best system for meeting system requirements.

Meteoroid Protection

A reliability study to determine probability of meteoroid penetration on space radiators with no meteroid protection, and with 0.10 inch-thick

[1]Reference 4

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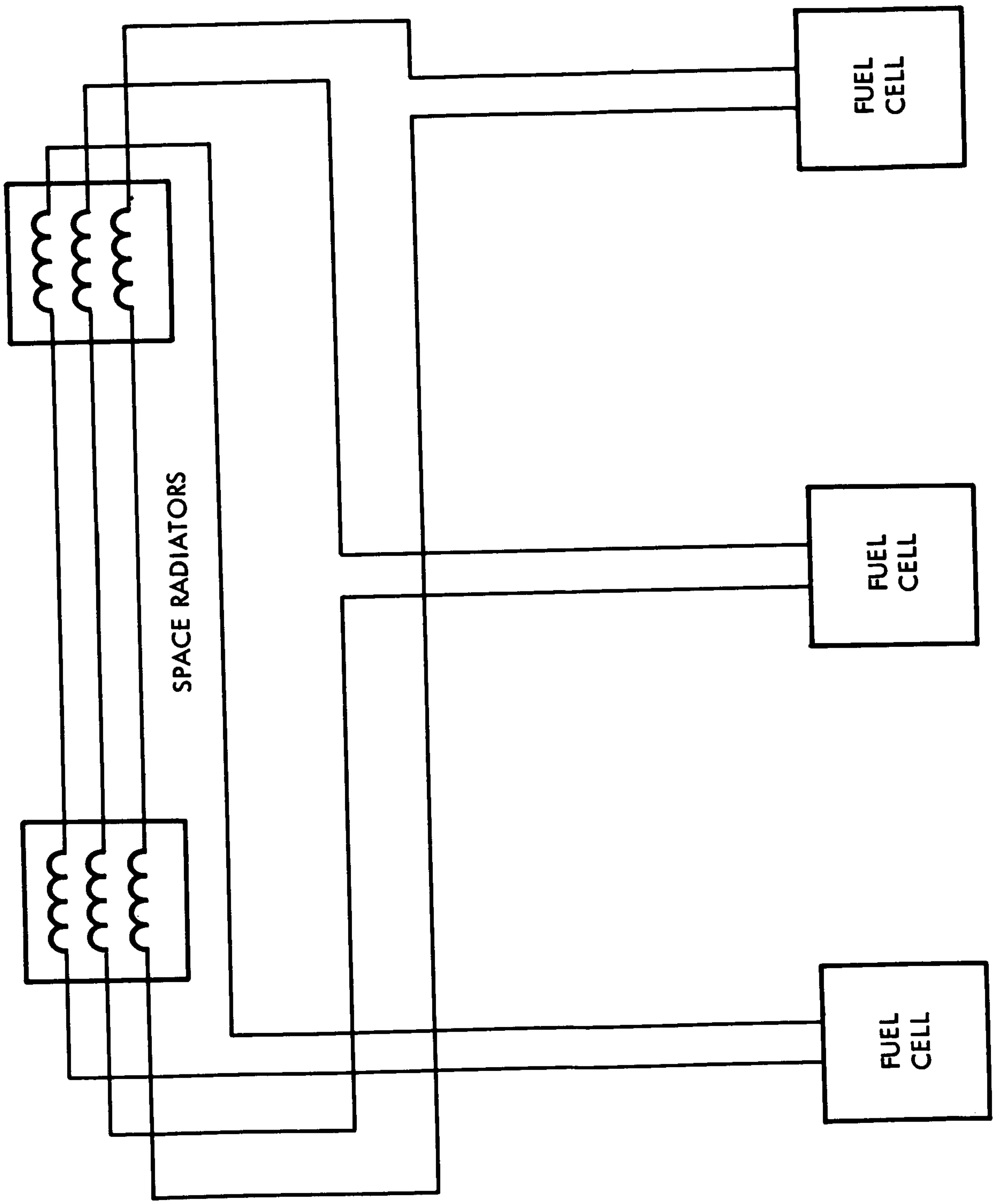

Figure 18. Space Radiator Configuration 1 - Two-Radiator, Single Path

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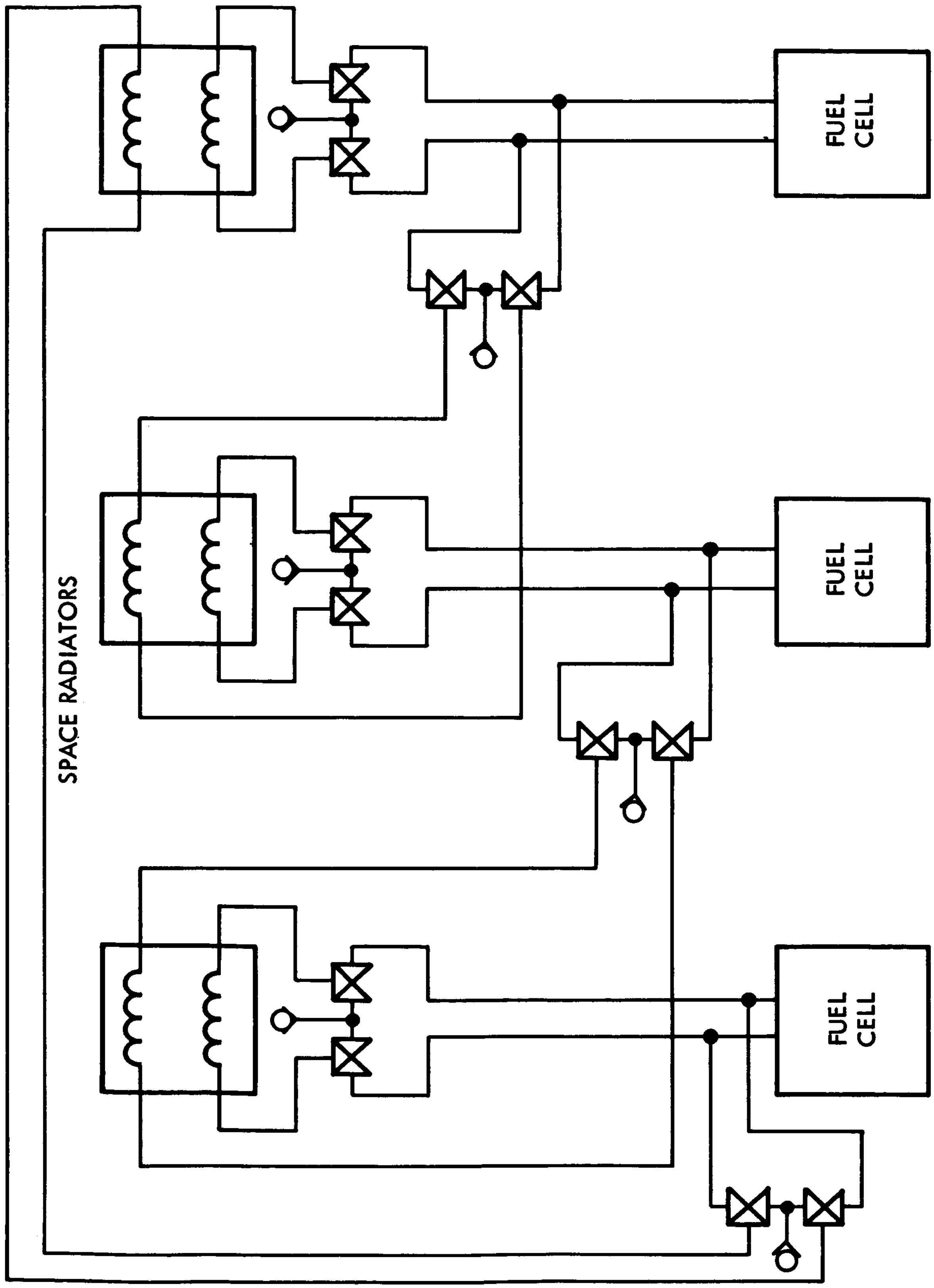


Figure 19. Space Radiator Configuration 2 - Three-Radiator, Redundant Path

[redacted]

tube walls was conducted. A summary of the reliability results and analysis are as follows:

Reliability of the electrical power subsystem with no meteoroid protection = 0.99977.

Reliability of the electrical power subsystem radiator with 0.100 thick tube walls ≅ 0.99977.

Since these results indicate that the EPS radiator reliability, with no meteoroid protection, satisfies the apportioned reliability requirements, redundant radiator loops would not appreciably enhance the system reliability. The detailed calculations supporting these reliability figures are as follows:

Probability of Meteoroid Penetration Analysis

<u>Case 1 - Tube Wall Thickness: 0.032 inch</u>

$$P/D = 3.5$$

$$\text{Vel} = 20 \text{ Km/sec}$$

$$\text{Semi-infinite target factor} = 1.25$$

$$\text{Tube-wall thickness} = 0.032$$

$$\text{Diameter of particle} = 0.032/1.25 \times 3.5 = 0.00731 \text{ in}$$

$$\rho \text{ of particle} = 3.5 \text{ gm/cc}^{1}$$

$$\text{Mass} = 1/6\,\pi d^3 \text{ in}^3 \times \rho \text{ gm/cm}^3 \times 16.387 \text{ cm}^3/\text{in}^3$$

$$3.1416\,(7.31 \times 10^{-3})^3\; 3.5 \times 16.387$$

$$= 0.523 \times 390.62 \times 10^{-9} \times 0.57.354$$

$$= 1.2824 \times 10^{-5} \text{ gm}$$

$$\text{Part/M}^2\text{/sec} = 10^{-8}$$

[1]Reference 5

[redacted]

Probability = $10^{-8}/10.76 \times 1.2 \times 10^{6}$

= 0.001115/sq ft

Three radiator loops or 0.524/3 = 0.18 sq ft critical area per loop

0.001115/0.18 = 0.00617 or 0.99383

Reliability of radiator loop = $R_1{}^3 + 3R^2 (1-R)$

0.98149 + 0.01828 = 0.99977

<u>Case 2 - Tube Wall Thickness: 0.100 inch</u>

P/D = 3.5

Vel = 20 Km/sec

Semi-infinite target - 1.25

Tube wall thickness = 0.1

Diameter of particle = 0.1/1.25 x 3.5 = 0.0228 in

ρ of particle = 3.5 gms/cc

Mass = $1/6\, \pi d^3 \times \rho \times 16.387$

= $3.14/6\ (2.28\ 10^{-2})^3 \times 3.5 \times 16.387$

= $0.523\ 11.85\ 10^{-6} \times 57.354$

= 3.5545×10^{-4} gm

Part/M^2/sec = 10^{-9}

Probability = $10^{-9}/10.76 \times 1.2 \times 10^{6}$

= 0.000111/sq ft

Three radiator loops or 0.524/3 = 0.18 sq ft critical area per loop

[redacted]

$$0.000111/0.18 = 0.000617 = 0.999383$$

$$\text{Reliability of radiator loops} = R_1{}^3 + 3R^2\,(1-R)$$

$$0.998149 + 0.001828 = 0.0999977$$

Note:

P/D = penetration depth per characteristic dimension of projectile

Km = thousand meters

ρ = density in grams per cubic centimeter

Combined System Study

A study was completed on the advisability of integrating radiators for the environmental control and electrical power subsystems. This analysis resulted in the conclusion that a non-integrated approach was advantageous for the following reasons.

It was subject to fewer first-order failure modes.

It has a greater tolerability to failures.

It precludes interactions of subsystems.

STABILIZATION AND CONTROL SUBSYSTEM

Analysis of the stabilization and control subsystem (SCS) has considered only faulty electronic outputs and inputs of major SCS blocks. The effect of each malfunction on mission success and compensation for it are presented in Table 17. "Repair if possible" means to use a redundant circuit, use a spare, or repair. The final list of on-board redundancies, spares, and spare parts has not yet been defined.

The effect of a failure on the mission and on crew survival will depend on the conditions under which the failure occurs. In most instances, if a malfunction is detected, there will be time to make intelligent decisions. However, there will always be the possibility of a dangerous failure at a critical moment. The likelihood of such an occurrence will be reduced through a continuous updating of this analysis.

The probability of a malfunction occurrence was not considered. By making dangerous possible malfunctions evident, this report should cause design changes which will reduce this probability. Later failure analyses will include the failure-probability factor.

Table 17. Stabilization Control Subsystem Failure-Mode Analysis

Source of Signal	Signal and Destination	Malfunction	Result	Alternate Mode of Operation	Effect on Mission
Guidance and Navigation System (G & N) Interface	"Precision-roll command," To SCS electronics	Open, or short to ground	Hardover[1]	Manual control or change mode to IRP stabilization	Increase in work load of crew.
	Heading and elevation error for ΔV^2 To SCS display, attitude error	Open	Gross error	Use attitude display, then repair, or repair and recompute	Delay or small error in direction of ΔV; increased use of fuel.
		Open	Small error	Would be corrected at time of next ΔV	Negligible, except for increase in use of fuel and crew work load.
	Engine thrust propulsion time-to-go To display (not known at this time if G & N or SCS)	Open	Gross error	Use DSIF[4] information	None except for increase in work load.
		Open	Small error	Would be corrected at time of next ΔV	None except for increase in work load.

Table 17. Stabilization Control Subsystem Failure-Mode Analysis (Cont.)

Source of Signal	Signal and Destination	Malfunction	Result	Alternate Mode of Operation	Effect on Mission
Guidance and Navigation System (G & N) Interface (Cont.)	Heading elevation or roll attitude To SCS display (through Euler angle converter)	Open, or short to ground	Hardover	Use IRP reference; correct malfunction if possible	Negligible, assuming other signals good; could result in abort if other signals aren't good.
	Attitude error (three body axes) To SCS display and SCS electronics	Open, or short to ground	Hardover	Use IRP attitude mode if time is not available to correct malfunction	At critical time this malfunction would be catastrophic; otherwise would indicate an abort, or not attempt to land on moon.
	ΔV and ΔV small To display (not known at this time if G & N or SCS display	Not known	Signal to display in error	Crew would determine if malfunction affects G & N engine ON-OFF; if control is valid, proceed; if not or if SCS is in use insert best ΔV available to SCS	Increase in work load, providing DSIF is checked before each ΔV.

Table 17. Stabilization Control Subsystem Failure-Mode Analysis (Cont.)

Source of Signal	Signal and Destination	Malfunction	Result	Alternate Mode of Operation	Effect on Mission
G & N	Thrust ON-OFF To SCS electronics	Not known	Engine fails to ignite or shut off	Override manually	The ΔV would not be as accurate if manual, but probably could be corrected later; increase in work load probably not serious.
Euler Angle Generator	Attitude (H, E, ϕ)[5] To SCS displays	Open or short to ground	Hardover	Stabilize manually using rate display; use θ_c, ϕ_c, ψ_c[6] valid; repair if possible; use G & N reference if possible and required	If G & N attitude reference is not available, g's and entry corridor information is probably not valid; if H, E, or ϕ from Euler angle generator is not good, it is believed crew could not survive superorbital-velocity entry.

Table 17. Stabilization Control Subsystem Failure-Mode Analysis (Cont.)

Source of Signal	Signal and Destination	Malfunction	Result	Alternate Mode of Operation	Effect on Mission
Euler Angle Generator (Cont.)	Body axes torquing commands (p, q, r)[7] To IRP (SCS)	Open or short to ground	Hardover	Disengage SCS; stabilize with emergency controls and rate display	A hardover during entry could be catastrophic; an open during entry would probably not prevent a successful completion of entry, using emergency control and g-information.
Inertial Reference Package (IRP)	Body axes attitude command To SCS display and SCS electronics	Open or short to ground	Hardover	Use G & N reference if available; if G & N is not available, disengage SCS, then stabilize with rate and emergency control and repair	If G & N is not functional, abort has probably been made; if repair can be made, safe return can be accomplished; if hardover occurs during entry, might or might not be catastrophic.

Table 17. Stabilization Control Subsystem Failure-Mode Analysis (Cont.)

Source of Signal	Signal and Destination	Malfunction	Result	Alternate Mode of Operation	Effect on Mission
Inertial Reference Package (IRP) (Cont.)	Body axes attitude rate, To SCS display and SCS electronics	Open or short to ground	Hardover	Switch to rate gyros; if not usable, disengage SCS, stabilize using displacement display and emergency control	Effect would depend on conditions of malfunction; if time to repair or go to rate gyros, effect is negligible, could be catastrophic during critical phase of entry.
Horizon Scanner	Pitch, roll, attitude command To SCS electronics	Open or short to ground	Hardover	Use inertial attitude reference, either SCS or G & N	Increase in fuel and/or power consumption not dangerous; no need to abort.
Sun Sensor	Pitch, yaw, attitude command To SCS electronics	Open or short to ground	Hardover	Use alternate sun sensor, G & N, or SCS attitude reference	Failure of both sun sensors would increase power consumption, probably restrict some mission phases or tasks.

Table 17. Stabilization Control Subsystem Failure-Mode Analysis (Cont.)

Source of Signal	Signal and Destination	Malfunction	Result	Alternate Mode of Operation	Effect on Mission
Rate Gyro Package	Body rates To SCS displays and SCS electronics	Short to ground	Hardover	Repair or switch to IRP as rate reference, if it is functional	Effect of rate gyro failure depends on conditions, it will be almost impossible to make large ΔV without rate, a successful entry might be made with only one axis inoperative.
Accelerometer	Longitudinal acceleration To SCS electronics	Not known	Small error or large positive error	Use ON-OFF signal from G& N in subsequent ΔV's	Higher rate of power consumption due to more usage of G & N and error in trajectory; no need to terminate mission or abort.
		Not known	Large error	Use manual shut-off; use G & N in subsequent ΔV's	

Table 17. Stabilization Control Subsystem Failure-Mode Analysis (Cont.)

Source of Signal	Signal and Destination	Malfunction	Result	Alternate Mode of Operation	Effect on Mission
SCS Controls Used to Adjust SCS	SCS mode select, deadband adjust, limiter adjust, hi-lo jet select To SCS electronics	Switches fail to open, fail to close, or short to ground	Proportional adjustments in error or short to ground	Each of these controls is redundant; the other controls might or might not be functional depending on nature of the failure	Depending on conditions of failure effect on mission and crew survival varies from negligible to catastrophic; might indicate abort.
SCS Controls Which Control Motion of Vehicle	Thrust ON-OFF and proportional rate command, three axes translation command. To SCS electronics	Switch fails to open or close or shorts to ground	Proportional signal too high or low	Use redundant control if functional; if not, use emergency control	Cannot accomplish translation except ullage; possible abort; crew survives unless malfunction occurs at critical time.
SCS Emergency Controls	Engine ON-OFF To SM II propulsion engine emergency coils	Switch fails to open or close or shorts to ground	Inability to control vehicle	Use redundant control if possible; repair if possible	Since emergency system is the last means of control, if it fails at a time when it cannot be repaired, the mission fails and the crew does not survive.

Table 17. Stabilization Control Subsystem Failure-Mode Analysis (Cont.)

Source of Signal	Signal and Destination	Malfunction	Result	Alternate Mode of Operation	Effect on Mission
SCS Emergency Controls (Cont.)	Vehicle pitch-yaw To SM II propulsion engine gimbal actuators	Switch fails to open or close or shorts to ground	Inability to control vehicle	Use redundant control if possible; repair if possible	Since emergency system is the last means of control, if it fails at a time when it cannot be repaired, the mission fails and the crew does not survive.
	Vehicle body rates To CM, SM II high level, reaction jet emergency coils	Switch fails to open or close or shorts to ground	Inability to control vehicle	Use redundant control if possible; repair if possible	Since emergency system is the last means of control, if it fails at a time when it cannot be repaired, the mission fails and the crew does not survive.

Table 17. Stabilization Control Subsystem Failure-Mode Analysis (Cont.)

Source of Signal	Signal and Destination	Malfunction	Result	Alternate Mode of Operation	Effect on Mission
SCS Emergency Controls (Cont.)	Ullage To SM II high level reaction jet emergency coils	Switch fails to open or close or shorts to ground	Inability to control vehicle	Use redundant control if possible; repair if possible	Since emergency system is the last means of control, if it fails at a time when it cannot be repaired, the mission fails and the crew does not survive.
SCS Electronics	Thrust ON-OFF and PROPORTIONAL To propulsion engine, LPM SM I SM II	Engine fails to ignite or shut off, or proportional control fails to modulate thrust	Inability to control thrust	In case of LPM, if engine does not shut off, close fuel supply; if it will not ignite, repair if possible; otherwise abort	Mission terminated; crew may or may not survive, depending on conditions.
	Vehicle rate command To propulsion engine gimbal actuators,	Open	Hardover	If LPM - stop fuel to engine, repair if possible, otherwise abort; if SM I, abort; if SM II, use emergency control; repair if possible	Mission terminated; crew may or may not survive, depending on conditions.

Table 17. Stabilization Control Subsystem Failure-Mode Analysis (Cont.)

Source of Signal	Signal and Destination	Malfunction	Result	Alternate Mode of Operation	Effect on Mission
SCS Electronics (Cont.)	pitch and yaw, LPM, SM I, SM II				
	Vehicle rate commands To command module reaction jets	Open	Hardover	Opposing signals would result in excessive use of fuel and would be automatically monitored; SCS will be disengaged in that axis; use emergency system	Negligible
	Vehicle rate commands To SM II reaction sets, low level and high level	Open	Hardover	If time allows, turn off fuel or SCS, repair, or use emergency control; if time does not allow, use emergency system which disengages SCS by axis	Increased work load; accurate navigational sightings might be difficult in emergency, but crew should be able to accomplish a safe abort.

Table 17. Stabilization Control Subsystem Failure-Mode Analysis (Cont.)

Source of Signal	Signal and Destination	Malfunction	Result	Alternate Mode of Operation	Effect on Mission
SCS Electronics (Cont.)	Translation, except ullage To reaction sets, high level, SM II	Open	Hardover	Shut off fuel; repair if possible	If repair cannot be accomplished, translation maneuver cannot be made.
	Ullage To reaction sets, high level, SM II	Open	Hardover	Shut off fuel and repair if possible; if not, disengage SCS, use the emergency control	Possible abort, crew survives.
		Open	Hardover	Use emergency ullage control system to complete ΔV, then repair if possible	Increased work load.
Power Converter	Power To SCS	Not known	Loss of voltage, reduced voltage	Automatic switch over to redundant converter	Crew might decide to abort after failure of one; failure of both would be catastrophic.

Table 17. Stabilization Control Subsystem Failure-Mode Analysis (Cont.)

Source of Signal	Signal and Destination	Malfunction	Result	Alternate Mode of Operation	Effect on Mission
Pressure Instruments	Altitude, altitude error, altitude rate To visual displays	Not known	Display information incorrect, slightly or grossly	To some extent the information from these instruments is redundant with other information; crew must sort the good from the bad	Probably none, except some increase in work load.
Displays (Displays are redundant for each quantity; crew can compare one quantity with another.)	Attitude information, attitude, attitude error, attitude rate To visual displays	Assuming information from the sensor to be correct, any quantity could be shown incorrectly on both displays or correctly on one and not the other	Ambiguity	If one display of any of these quantities is incorrect and can be identified, repair or ignore it; proceed with the information through other applicable instruments	These displays are very important during critical phases, especially during emergency control of large ΔV; if both displays are inoperative, an abort is suggested and should be successful, if the display only is in error.

Table 17. Stabilization Control Subsystem Failure-Mode Analysis (Cont.)

Source of Signal	Signal and Destination	Malfunction	Result	Alternate Mode of Operation	Effect on Mission
Displays (Cont.) (Displays are redundant for each quantity; crew can compare one quantity with another.)	Range and range rate To visual displays	Not known	Incorrect display	DSIF could provide some information which would be partially redundant with range and range rate; visual contact might make possible a rendezvous; if good information is not available, do not attempt rendezvous or lunar landing	Mission might be terminated; crew should be able to accomplish safe reentry and recovery.
	Acceleration To visual displays	Not known	Incorrect display	Use best information	Should only add a confusion factor.
	Entry corridor position To visual displays	Not known	Incorrect display	Use best information such as acceleration; time, etc., to identify correct display	Entry from an earth orbit probably could be accomplished without this information; returning from the

Table 17. Stabilization Control Subsystem Failure-Mode Analysis (Cont.)

Source of Signal	Signal and Destination	Malfunction	Result	Alternate Mode of Operation	Effect on Mission
Displays (Cont.) (Displays are redundant for each quantity; crew can compare one quantity with another.)					moon, crew could probably not make a safe earth reentry.

Notes:

1. Hardover = maximum error to which the system can respond
2. ΔV = Velocity change
3. IRP = Inertial reference package
4. DSIF = Deep space information facility
5. H, E, ϕ = Total Euler angles with respect to inertial reference
6. θ, Φ, ψ = Angles with regard to spacecraft body axes
7. p, q, r = Angular rates with respect to spacecraft body axes

EARTH LANDING SUBSYSTEM

Pyrotechnic Requirements

An evaluation was made to determine the number of pyrotechnic initiators needed for each of the earth landing subsystem functions. Since a parallel channel sequencer will be used, one initiator in each channel for each function will provide the required redundancy to meet the system-reliability requirements.

System Function	Pyrotechnic Initiators Required
No 1 drogue chute mortar initiation	2
No 1 drogue chute release	2
No 2 drogue chute mortar initiation	2
No 2 drogue chute release	2
Main chute deployment (3 pilot chutes)	6
Parachute bridle release	2
Upper heat shield jettison initiation	2
Lower heat shield release	2
TOTAL	20

Pyrotechnic Ignition

A qualitative reliability study of explosive-bridge-wire versus hot-wire ignition of pyrotechnic devices was performed. The results, summarized in Table 18, reveal that either method when properly designed, would meet reliability and safety requirements.

[redacted]

Table 18. Summary of Considerations of EBW and Hot-Wire Ignition Methods

System	Advantages	Disadvantages
EBW	Inherently safe Acceptable electrical reliability High probability of ignition Low sensitivity to high temperature and shock (does not contain primary explosive)	Gap tube outgassing Shut down transients Difficult to check Radiation effects unknown Low temperature effects unknown Probable need for coded signal
Hot-Wire	Simple Fully developed state-of-the-art Economical High electrical reliability Easy to check Light weight if safe-arm not required	Safety precautions required More sensitive to high temperature and shock unless properly protected (contains primary explosive) Radiation effects unknown Low temperature effects unknown

[redacted]

Access Hatches

Several methods for securing spacecraft access hatches have been evaluated. One method involves ingress and emergency egress through a 7.7 square-foot door. This approach requires a quick opening latch mechanism to secure and seal the door during the mission. The proposed mechanism weighs 40 pounds in addition to the weight of the door. The question of whether the crew could handle this mass during an emergency has been raised. The second method involves ingress through a 7.7 square-foot door located in turn in a 21 square-foot blow-out panel that would be employed for emergency egress. Latching of the ingress door would be accomplished through cam-lock levers, worm gears, mechanical actuators, and other securing devices. Each of these approaches is satisfactory from a reliability viewpoint.

Parachute Deployment

A reliability analysis was made to evaluate three different methods of deploying the cluster of three main parachutes. The first method considered was that proposed by Northrop Ventura. It consisted of two identical drogue parachutes, with each having the capability of deploying the cluster. At S&ID's request additional studies were performed by Northrop Ventura. A second method studied was the same as the first, except that only one drogue was used; a third method considered included no drogue, the main parachute being deployed individually by the use of mortars.

The results of the evaluation were as follows:

> If a drogue system is to be used, two drogues must be employed to provide the redundancy required to meet the system reliability requirements.
>
> The proposed method of deploying the main cluster by use of a single drogue fails to meet the system-reliability requirement because the deployment of the whole cluster is dependent on the single action of the drogue uncovering and pulling out all three parachutes.
>
> A drogue is desirable for two reasons. It provides stability, and permits a lighter main-parachute construction.
>
> Individual deployment of the main parachute using mortars provides the redundancy required to meet system requirements.

[redacted]

Considering this information, the Design Review Board decision was to develop a system consisting of two drogues supplemented by individual deployment of the three main parachutes.

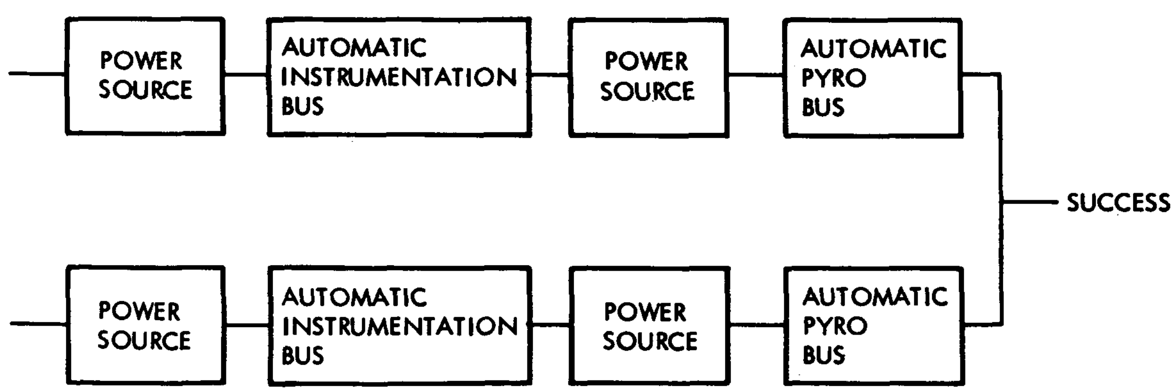
Boilerplate No 6 Sequencer

The three following sequencing systems for Boilerplate 6 were evaluated for reliability.

> Two parallel automatic systems with radio-command override for several functions.
>
> A single power source supplying redundant components.
>
> An automatic system in parallel with a radio command system.

Based on the following descriptions and analyses of the three systems, it was recommended that the first system be utilized in BP 6.

System 1 - Two Parallel Automatic Systems With Radio-Command Override for Several Functions



The reliability of System 1 is 0.99999, using standard-failure-rate data. The numerical analysis does not include the power sources but does include the EBW firing units. The system is completely redundant except for the radio-command receiver which operates from one of the power sources. Maintaining parallel circuits eliminates the majority of electrical circuit interactions.

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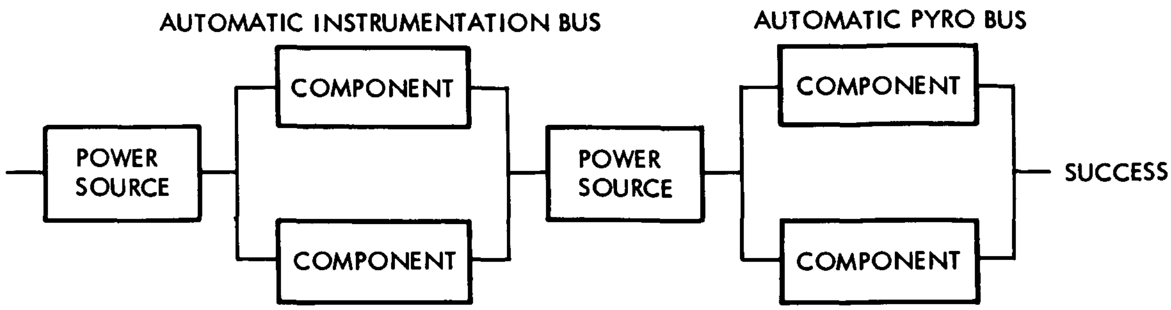
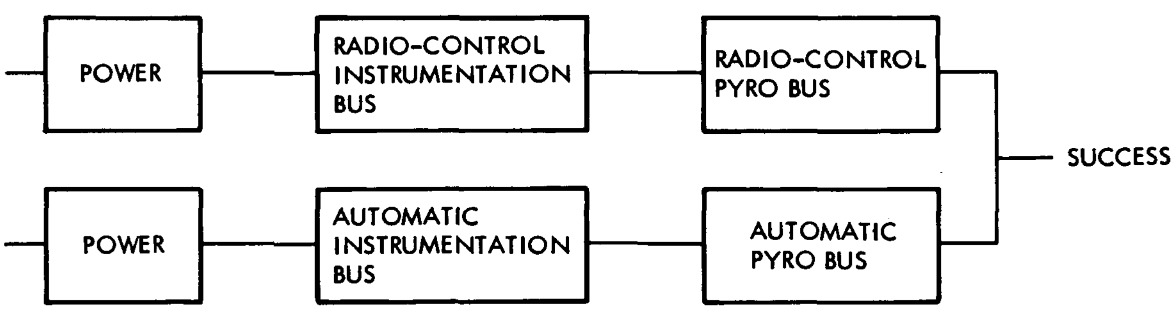
System 2 - Single Power Source Supplying Redundant Components.



System 2 has two power sources, although both are required for success. A detailed schematic of the system was not available, therefore, a qualitative analysis was conducted.

A series of duplicate components is considered more reliable than parallel systems of series components, because of the allowable paths for success. Since the reliability of System 1 was quite high, it is assumed that lack of duplicate power sources would make this system inferior from a reliability standpoint. A short circuit in the system would result in complete system failure and possibly cause a fire in the vehicle being tested.

System 3 - Automatic System In Parallel With a Radio-Command System



System 3 is not considered as reliable as System 1, because System 1 has parallel automatic systems with radio-controlled override capability for those functions (in both systems) considered feasible for decision by a ground crew. System 3 does not contain the redundancy of System 1, and it is considered doubtful that the ground crew could make the proper decisions at the proper time for all of the functions.

Since no schematic was available for System 3, no numerical analysis was made for it.

Comparative Earth-Landing Sub-Systems

A reliability evaluation was made of comparative earth landing systems. One trade-off was between parachute and paraglider; a second trade-off was between a launch escape system and ejection seats with personal parachutes. The reliability logic diagrams used in the evaluation along with numerical results are shown in Figure 20.

The results of the evaluation are as follows, the systems evaluated being listed in order of descending reliability:

> Separately deployable parachute cluster, launch escape system and personal parachutes for crew.
>
> Paraglider, launch escape system and personal parachutes for crew.
>
> Separately deployable parachute cluster and ejection seats for crew.
>
> Paraglider and ejection seats for crew.

Facts and Assumptions Used in Evaluation

High-Altitude-Recovery Considerations Probability-of-deployment of the parachute cluster is based on the probability that at least two of the three chutes open. Reliability of each chute (0.998) is based on Mercury data and Northrop Ventura estimates of present state-of-the-art. The same value (0.998) is used for each drogue chute.

The value (0.9995) assigned to deployment of the Paraglider is based on the positive actuation provided by inflation of the booms and configuration control afforded by sequenced release.

The values selected for the landing hazard factors reflect an analysis of 1,388,852 live jumps from 1951 to 1957 suing the T-10 extended-skirt troop parachute. During this period 21 fatalities occurred due to local landing hazards rather than parachute failure. The higher number assigned to the paraglider is based on the fact that it can be maneuvered to miss local ground hazards.

The principle difference in complexity between the Paraglider and the parachute cluster lies in the flight control subsystem. The flight control

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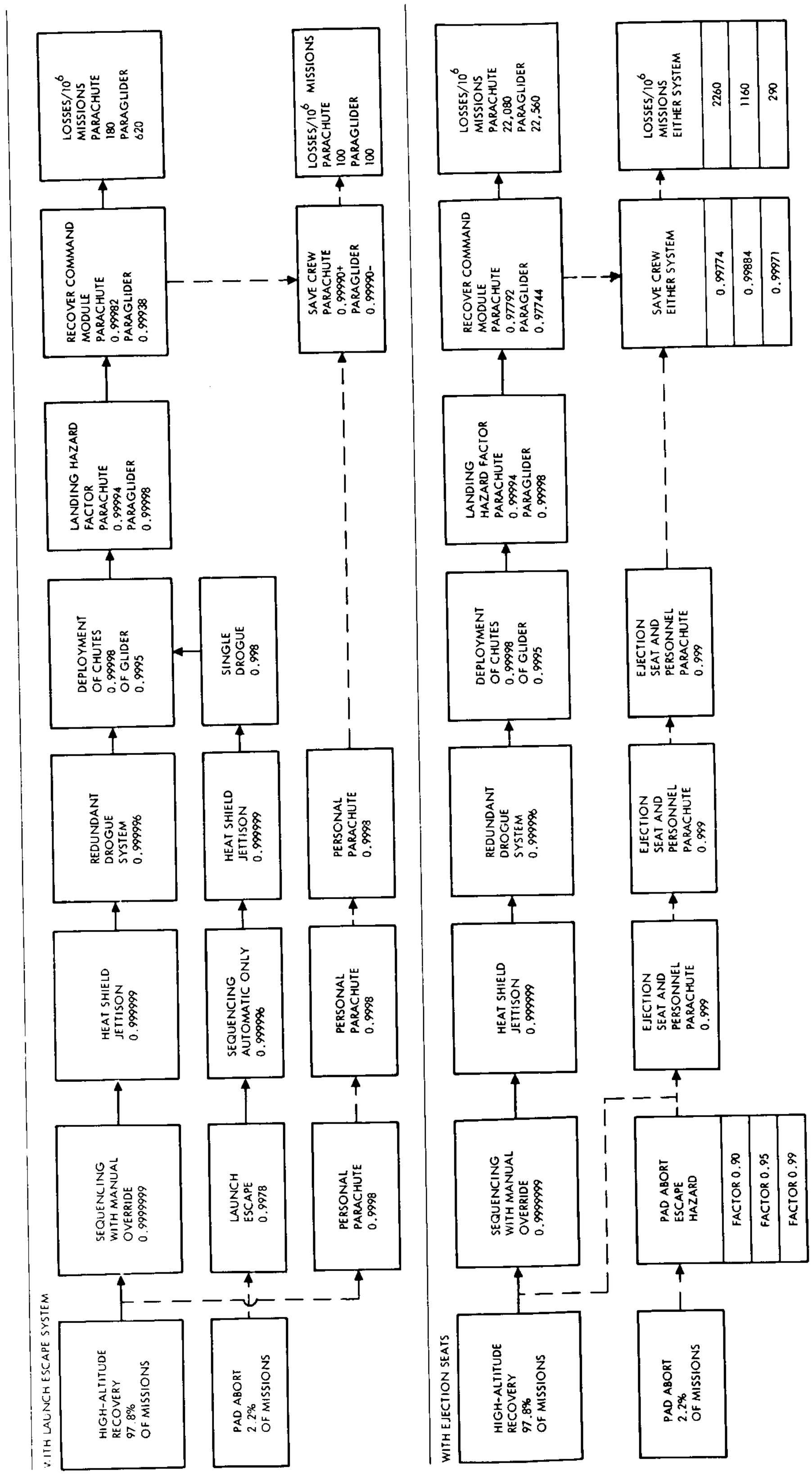

Figure 20. Reliability Evaluation of Comparative Earth Landing Subsystems

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[redacted]

subsystem in the paraglider configuration is not needed in an earth landing system that uses parachutes. In the event of a failure of the paraglider flight control subsystem, the Paraglider would return to an attitude which provides a landing equivalent to the parachute (no ability to avoid local hazards). The envisioned control subsystem would be similar to the highly reliable systems used in aircraft with the exception that air motors would be utilized to provide power boost. The system would also include control cables, pulleys, capstans, and a side arm controller.

The other subsystems would be comparable to each other in complexity and reliability. The drogue system and electrical sequencing systems would be equivalent. The Paraglider landing gear subsystem would be directly traded off with the impact attenuation (shock struts) subsystem. The inflation system, either blow-down or gas generator, would be traded off with the extraction subsystem of the parachute.

Pad-Abort-Recovery Considerations. A pad abort occurs on 2.2 percent of missions.

Without a launch escape system, the command module is not recoverable upon a pad abort.

The probability of the crew surviving a pad abort by use of ejection seats is several orders of magnitude lower than the probability for other elements in the system. Three values (0.90, 0.95 and 0.99) are given to show the effect on the probability of crew survival in the range of values considered applicable. The range selected is based on the number of fatalities that have actually occurred in airplanes equipped with ejection seats and on the hazards inherent in the use of low trajectory ejection seats in an area such as the pad during an abort under emergency conditions.

Using the launch escape system, the assumption is made that, during pad abort, there is not sufficient time to utilize man's override capability in the sequencing system or the redundant drogue.

The values used for personal parachute (0.9998) and ejection seat (0.999) reliabilities are based on historical data. It should be noted that varying these values between the two extremes shown has a very insignificant effect on the probability of recovering the crew since the chutes are only used in the event of a system failure.

Failure-Mode Analysis

A failure-mode analysis was made of the earth landing subsystem. A schematic block diagram of the system is shown in Figure 21. One half of the parallel channel sequencer is shown as System A; System B is identical to provide redundancy.

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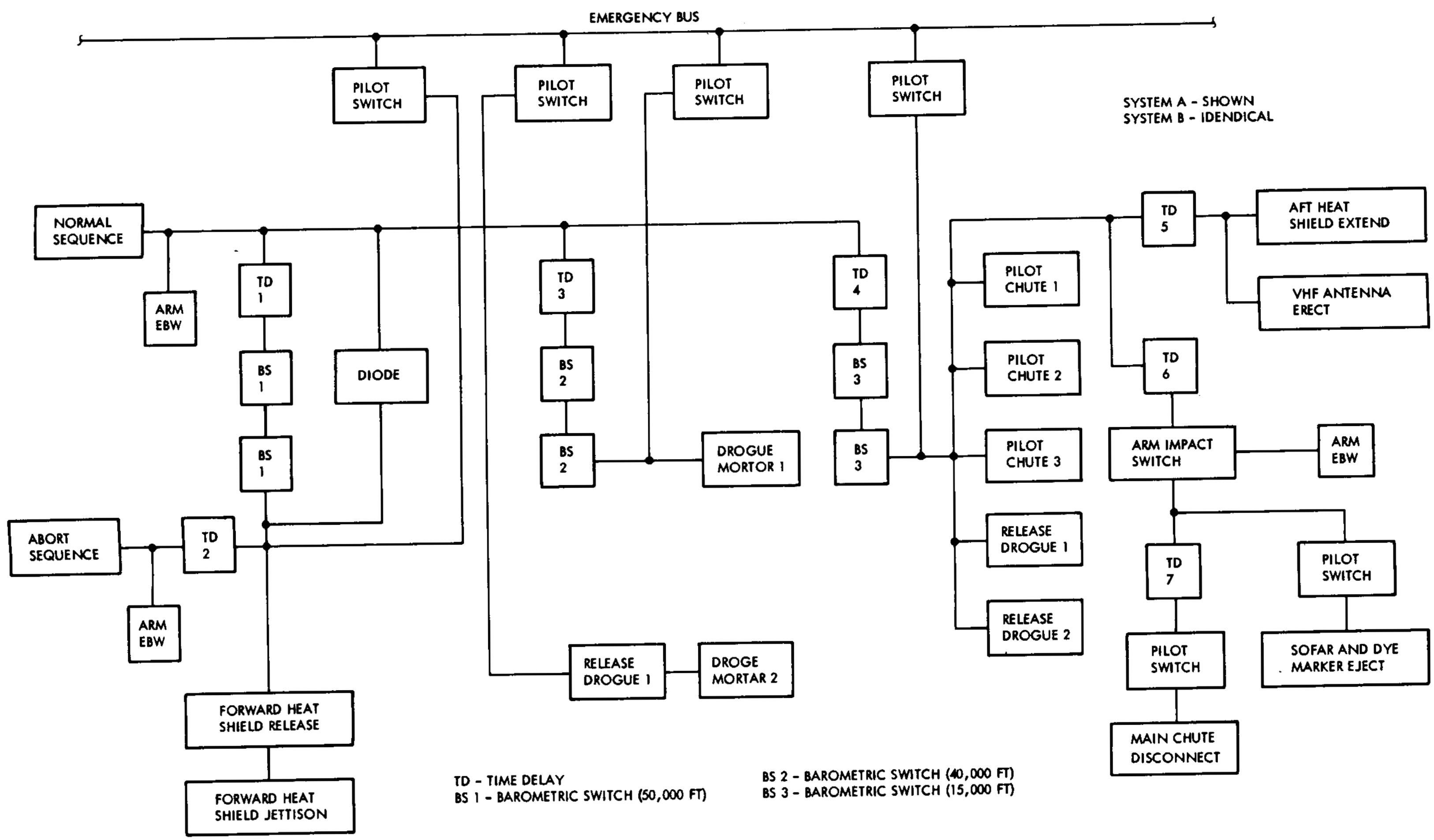

Figure 21. Earth Landing Subsystem Schematic Block Diagram

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[redacted]

Table 19. Earth Landing Subsystem Failure Mode Analysis

System A Component*	Failure Mode	Probable Cause	Effect Upon: Mission Success	Effect Upon: Crew Survival	Remarks
Power source	No power	Failed component	None	None	Redundant - complete failure in system A; system B would be available.
Arming switch	Does not close	Failed component	None	None	Redundant - system A would not arm; system B could still function normally.
Time delay no. 1	Does not close	Failed component	None	None	Redundant - in system A, power would be supplied to 50K baro's with no bad effects; system B could still function normally.
50, 000-feet barometric switches	Both switches in h>50K	Failed component	None	None	Redundant - manual override could be used in system A; system B could still be operating normally.
	One switch in h>50K, other normal	Failed component	None	None	Redundant - manual override could be used in system A; system B would still be operating normally.
	Both switches in h<50K	Failed component	Depends on altitude		As soon as time delay no. 1 closed, forward heat shield would be released.
	One switch in h<50K, other normal	Failed component	None	None	Redundant - sequencer in system A will still function normally because of series connection; system B would be operating normally.
	One switch in mid-position, other normal	Failed component	None	None	Redundant - manual override could be used in system A; system B would operate normally.
Forward heat shield gas generator and cable cutter	No gas generated	Failed component	None	None	Redundant - system A would fail to release heat shield; system B would still operate and release heat shield.
Heat shield release cable	Does not release	Bind	Loss	Loss	Forward heat shield would not be released; drogues and main chutes could not be deployed; crew could survive by use of personal parachutes.
Heat shield latch mechanism	Does not release	Failed component	Loss	Loss	
Heat shield	Does not separate from command module	Fused to command module	Loss	Loss	
Time delay no. 3	Does not close	Failed component	None	None	Redundant - in system A, power would be supplied to 40K baro's with no bad effects; system B would still operate normally.

[redacted]

Table 19. Earth Landing Subsystem Failure Mode Analysis (Continued)

System A Component*	Failure Mode	Probable Cause	Effect Upon: Mission Success	Effect Upon: Crew Survival	Remarks
Pilot chute	Not deployed	Mortar failure	None	None	Pilot chute deploys main chute.
Main chute	Not deployed	Failed component	Depends on number that fail		Two of the three main chutes will support the command module. Crew would probably survive with one.
Time delay no. 5	Does not operate	Failed component	Loss	Loss	At same time main chutes are being deployed, lower heat shield is being released; this could cause the chutes to fail by overstressing. Crew could survive by use of personal parachutes.
Aft heat shield gas generator and cable cutter	No gas generated	Failed component	None	None	Redundant - system A would fail to release heat shield; system B could still operate and release heat shield.
Heat shield release cable	Does not release	Bind	Depends on velocity of impact		Lower heat shield would not be released, therefore would not be in position to absorb impact upon landing. Crew survival enhanced due to couch attenuation system.
Heat shield latch mechanism	Does not release	Failed component			
Heat shield	Does not separate from command module	Fused to command module			
Time delay no. 6	Does not operate	Failed component	None	None	Impact switch would be armed at same time chutes were being deployed. This would not be detrimental to system operation.
Impact switch	Does not arm	Failed component	None	None	Redundant - system A would not be able to release main chutes; system B could still arm switch.
Time delay no. 7	Does not operate	Failed component	None	None	Redundant - system A unable to release main chutes; system B could still operate and release chutes.
Pilot switch — main chute release	Does not operate	Failed component or man	None	None	Main chutes would fail to release on impact.
Main chute disconnect	Does not release	Failed component	None	None	Main chutes would fail to release from command module.
Pilot switch — sofar and dye	Does not operate	Failed component or man	None	None	Sofar and dye marker not ejected.

*System A is identical to system B.

[redacted]

Table 19. Earth Landing Subsystem Failure Mode Analysis (Continued)

System A Component*	Failure Mode	Probable Cause	Effect Upon: Mission Success	Effect Upon: Crew Survival	Remarks
40,000-feet barometric switches	Both switches in h>40K	Failed component	None	None	Redundant - manual override could be used in system A, system B would still operate normally.
	One switch in h>40K, other normal	Failed component	None	None	Redundant - manual override could be used in system A; system B would still operate normally.
	Both switches in h<40K	Failed component	Loss	Loss	As soon as time-delay no. 3 closed, drogue deployment would be initiated, but it would be halted because of the heat shield not being released at this time. Crew could survive by use of personal parachutes.
	One switch in h<40K, other normal	Failed component	None	None	Redundant - sequencer in system A will still function normally because of series connection; system B would still operate normally.
	One switch in mid-position, other normal	Failed component	None	None	Redundant - manual override could be used in system A; system B still operating normally.
Drogue no. 1 igniter	Does not operate	Failed component	None	None	Redundant - drogue no. 2 could be deployed.
Drogue no. 1	Not deployed	Does not open, rips, etc.	None	None	Redundant - drogue no. 2 could be deployed.
Time delay no. 4	Does not operate	Failed component	None	None	Redundant - power would be supplied to 15K baro's in system A; switch B still operating normally.
15,000-feet barometric switches	Both switches in h>15K	Failed component	None	None	Redundant - manual override could be used in system A; system B operating normally.
	One switch in h>15K, other normal	Failed component	None	None	Redundant - manual override could be used in system A; system B would still operate normally.
	Both switches in h<15K	Failed component	Loss	Loss	As soon as time delay no. 4 closed, the main chutes would try to be deployed but would be unable to because of the heat shield not being released. Crew could survive by use of personal parachutes.
	One switch in mid-position, other normal	Failed component	None	None	Redundant - manual override could be used in system A; system B still operating normal.

[redacted]

[redacted]

The analysis which follows (Table 19) is for normal re-entry and does not consider abort conditions. Failures of individual components and the probable cause of the failures are identified. The effects of the failure upon the success of the mission and the survival of the crew is noted, and the nature of the system's redundancy and the resulting situation are explained.

QUALIFICATION-RELIABILITY OPERATIONS

Test Models

Methods are presently being developed to determine the reliability of one-shot, high-cost devices when only small sample sizes can be justified for testing. The technique is based upon stress-versus-strength and performance-margin concepts, and can yield high confidence statements about the demonstrated reliability.

The stress-versus-strength technique is also being evaluated to define its applicability to the qualification-reliability demonstration program for other devices, including structures, heat shields, electro-mechanical, and electronic equipment.

A model is being established to analytically define required equipment test-time (in a particular combination of environments) as a function of the expected mission duration and the required reliability and confidence. This model will be employed to calculate the test time necessary to demonstrate reliability at a specified confidence and at the end of qualification-testing. It will also be used to show the amount of additional test time necessary to increase the statistical confidence to any desired value. The actual environmental tests and the sequence of exposures will closely simulate the Apollo lunar landing and earth return mission.

Flight-Test Operations Support

Reliability engineering support requirements for each field test site have been prepared. Included were office space, equipment, tear-down-analysis laboratory space, and the test equipment required in each area. Preliminary work statements and manpower estimates required to conduct this activity have been completed.

Procedure For Evaluation Of Commercial Test Laboratories

In a joint effort with the S-II Reliability Test group, a document is being prepared to define the procedures to be employed and the reliability requirements for evaluation of commercial test laboratories. Information from surveys conducted by either Apollo or Saturn personnel will be shared and recorded in a common document to preclude duplication of effort.

[redacted]

Test Accounting System

A plan has been prepared to identify all development, qualification, and reliability tests currently proposed by S&ID and Apollo subcontractors for spacecraft, subsystems, components, and GSE. Information gained through the identified tests will be employed to determine the adequacy of testing, number of hardware items to be tested, and the proposed schedules for completion of qualification test requirements. Test accounting forms, describing the number and types of tests currently planned for Apollo subcontractors, have been completed. When tabulations are completed, the information will be employed to determine the completeness (and any duplication) or proposed test programs to meet reliability demonstration objectives. Test accounting will be presented in the revised Qualification.

Qualification Status Report

Qualification status data has been compiled from information acquired from engineering and test groups. This information has been compiled into the contractually required Qualification Status Report and submitted to NASA. Because of the limited information available at this time, the list can only reflect schedule status to the major component level.

NASA/NAA Documentation Review Meeting

A review of the Apollo Reliability Test Plan was conducted on May 17 and 18 at NASA Headquarters, Washington, D.C. Through mutual agreement, the test plan is to be revised to place further emphasis upon off-limit, parameter-variability, life, and mission-profile simulation tests. Although these were contained in the previous issue of the test plan, only minor treatment was afforded each. Additional reorientation is required to show employment of factorial and other experimental designs as exploratory tests in the event that difficulties are encountered during qualification or reliability testing. The revised plan will define minimum test programs for each of the spacecraft subsystems.

Analysis Aid

To facilitate the retrieval, recording and processing of Apollo data, the following statistical programs have been established and are available for immediate use.

IBM 7090 Programs

Histogram Plotting on Cathode Ray Tube (CRT)
Process Evaluation (CRT)
Mean ($\bar{X}$) and Range (R) Charting

[redacted]

Percent Defective Charting
Mean and Standard Deviation Charting
Mean Test for Singly Classified Multiple Groups
Analysis of Variance (ANOVA) Factorial Design
Chi-Square Test of Independence
Life-Curve Identification
Burn-In Time Determination
Mean-Time-Between-Failures Plotting (CRT)
Linear Correlation of Data and Transforms (CRT)
Correlation Coefficients of First and Second Degree Curves
Parabolic Correlations (CRT)
Semi-Log Parabolic Correlation
Cubic Correlation (CRT)
Response Surface Plotting, Two Independent Variables (CRT)
Response Surface Calculations, Two Independent Variables
Response Surface Calculations, Three Independent Variables
Response Surface Calculations, Four Independent Variables
Attribute Correlations
Hypergeometric Sampling Plan Calculations
Queuing Problem Calculations

Recomp II Programs

Linear Programming Simplex Method
Matrix Inversion and Solution of Simultaneous Equations
Determinant Evaluation
Matrix Inversion (42 x 42 inches)
Simple Correlation Coefficients
Beta Function Program
Gamma Function
Two-way Analysis of Variance
Mean, Variances, Standard Errors, and Confidence Intervals
Multiple Linear Regression and Correlation Analysis
Transportation Problem
Least-Squares Curve Fit for the Exponential, Logarithmic and Power Function
A Monte Carlo "Proof"
Chebyshev Ploynomial Economization

<u>Computer Methods And Data Documentation</u>

A computer-oriented reliability program utilizing IBM 7090 and RECOMP-II computers, is being developed to support the Apollo Reliability project. This program encompasses description and comparison computer methods for circuit analysis and other allied studies.

Information of electronic and electro-mechanical designs is presently being developed. The computer output data will be used to evaluate the adequacy of design and support reliability design reviews.

A special study in support of the design of ground support equipment (GSE) is in progress. Participation in other program studies requiring computer techniques is being investigated.

To standardize reliability circuit-analysis studies and assure that essential information is consistently recorded, a general format for computer circuit analysis reporting has been developed. The required contents such as schematics, drawing numbers, parts lists, equivalent circuit diagrams, computer program printouts, and presentation of results are delineated. It is intended that S&ID studies, as well as subcontractor studies, follow this format.

Mathematical Reliability Model

A mathematical reliability model based upon Monte Carlo techniques has been developed as a reliability system analysis aid. Although the accuracy of the more detailed logic model cannot be achieved by employing this approach, simplicity in use and greater flexibility are the major advantages. As an example, only minor changes in the input data will be required to account for configuration changes. Print-outs will include, in addition to mission success and crew safety numerics, probability statements regarding the influence of any component in aborting a mission or inducing a safety hazard.

Use of the mathematical reliability model will also permit an evaluation of the effects on the spacecraft of variable reliability in a component, and will provide information for on-board maintenance studies, including those limitations imposed by a finite number of on-board spares.

SUBCONTRACTOR COORDINATION

The S&ID has initiated regularly scheduled monthly reliability meetings with all subcontractors. The purpose of these meetings is to review reliability progress at scheduled intervals, establish lines of communications at the working level, and consider possible solutions to various reliability problems.

Material Traceability and Configuration Accountability

In support of Apollo requirements, effort has been expended during this report period to develop a program controlling material traceability and configuration accountability. The significant features of the program (Figure 22) are aimed at accomplishing the following objectives:

Material Traceability

This deals with tracing and identifying material from the time of original procurement through all stages of fabrication until it appears in the end item. It will also trace any material identifiable by part number and serial or original manufacturer's lot number, to the assembly part number, and finally to the serial number of the spacecraft or end item of GSE in which it is installed.

Configuration Accountability

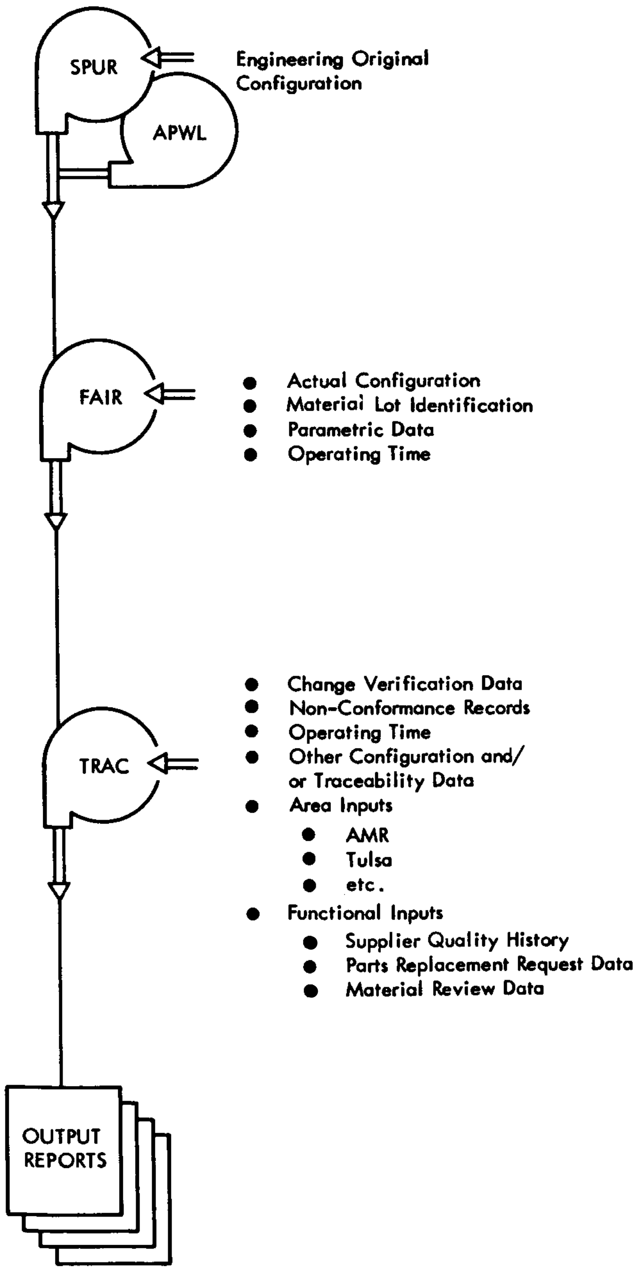
This deals with correlating actual configuration accomplished during manufacturing and assembly with the original paper configuration established by design engineering and engineering-configuration control. Its purpose is to be able to report on actual configuration as to actual part numbers and lot numbers used in each identifiable assembly.

The flow diagram (Figure 23) shows the mechanical functions and the responsibilities of the various organizations participating in the effort to control material traceability and configuration accountability system will be presented in a subsequent revision of SID 62-203, Apollo Reliability Program Plan.

Interservice Data Exchange Program (IDEP)

S&ID is now participating in the Interservice Data Exchange Program (IDEP). This program has been established to facilitate the interchange of reliability data among government agencies and contractors engaged in the development and manufacture of ballistic missiles and space vehicles. Under this program, each participating missile and space project contractor will submit copies of every test report within selected categories to the IDEP Data Distribution Center (DDC) where they will be microfilmed. The microfilms of the complete report, attached to a summary card, will be automatically distributed to all designated participating contractors and agencies which have previously expressed an interest in that particular subject. Classified information will not be transmitted through IDEP.

An average participating contractor will receive approximately seventy times as much data as contributed. Although this data may not always be precisely applicable to required performance and environment, IDEP will make it possible to examine test data developed and generated by other contractors which could reduce, eliminate, or modify our own testing.



SEPARATE PARTS USAGE RECORD
System responsibility:
Standards Engineering and Design Engineering. SPUR is an automation program on bill-of-materials and next-assembly information taken from engineering drawings.

AUTOMATICALLY PROCESSED WIRE LISTS
These lists are processed in conjunction with the SPUR program for the blue prints concerned with electrical or electronic wiring.

FABRICATION-ASSEMBLY-INSPECTION-RECORD
System responsibility:
Manufacturing and Quality Control. This is an automation program on the planning-ticket and inspection-records requirements.

TOTAL-RECORDS-ACCESS CONTROL
System Responsibility: Data Analysis Engineering. This is a data integration program to accomplish the task of utilizing (1) engineering configuration information from the SPUR program, (2) actual configuration and material traceability information from the FAIR program, and (3) other normal data inputs to provide the many reports required on:

Material Traceability
Configuration Accountability
Non-Conformance Data
Operating Time
Parametric Data

Such reports are presently being formulated to firm committments as a result of S&ID departmental needs as well as contractual requirements on the Apollo.

Figure 22. Material Traceability and Configuration Accountability Flow Diagram

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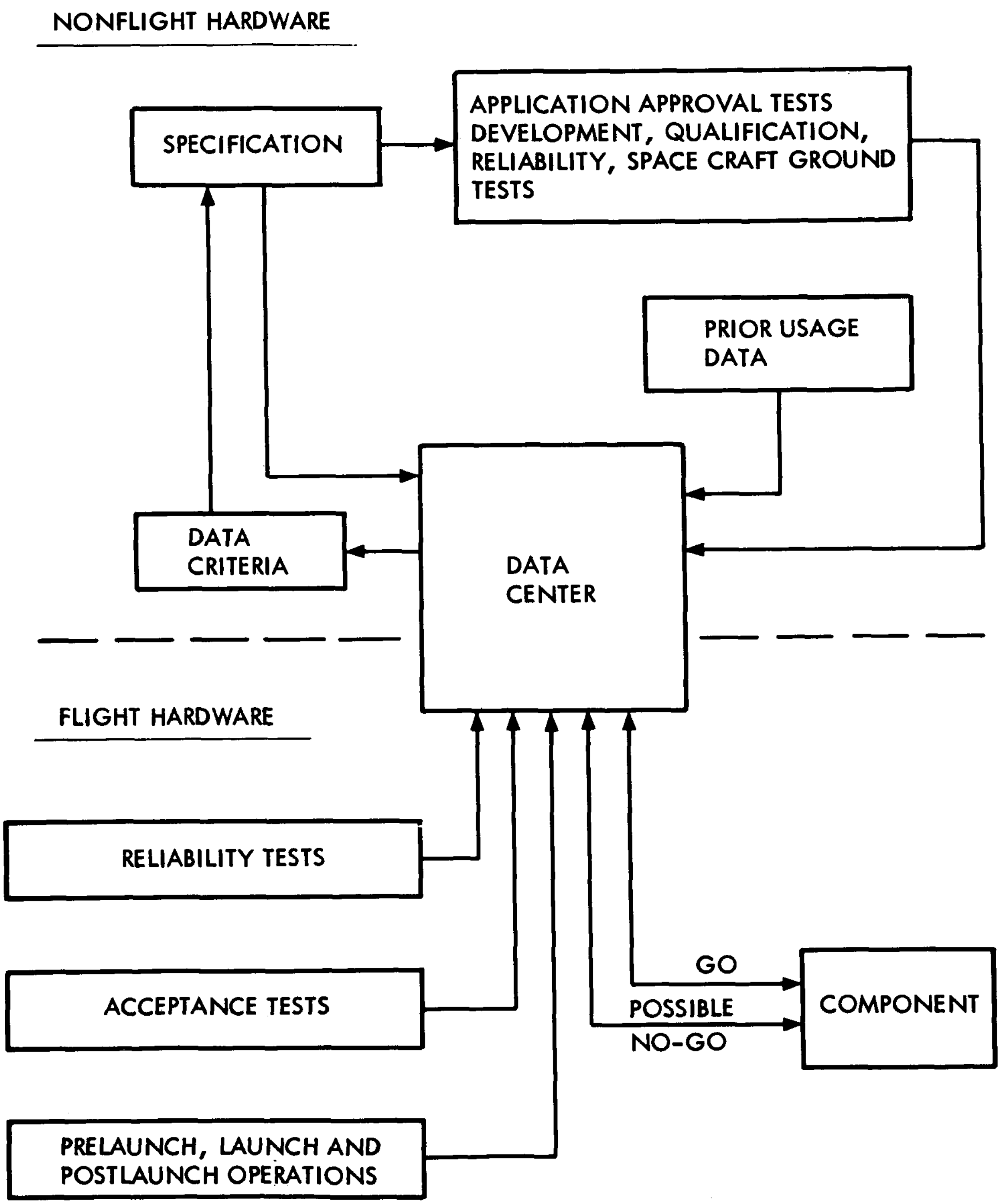

Figure 23. Typical Data Accumulation and Flow

MOTIVATION AND TRAINING

General indoctrination briefings on Apollo for new employees have been conducted during the past few months and are continuing on a required basis. The initial presentation of Computer Methods of Electronic Design Analysis began 17 April 1962, with a second presentation of the same course scheduled to commence in mid-July. Courses dealing with reliability mathematics as a part of reliability indoctrination (Course No. 5) have been initiated with various engineers from the reliability and design groups participating.

In order to better acquaint subcontractors with Minuteman parts, their application to Apollo, and their limitations, a symposium has been planned to be held at NAA/S&ID in mid-July. The symposium will be of one to two days duration and will include all subcontractors who are involved in the selection of electronic parts.

The following is a list of courses to be presented in support of the Apollo program. These courses generally are designed for adaptation to either detailed instruction or briefings.

- General Apollo Indoctrination
- Apollo Reliability Program Plan
- Computer Methods of Electronic Design Analysis
- Minuteman Standards and Parts with Application to Apollo
- Reliability Indoctrination for Reliability Engineers
- Design Ramifications in Reliability Apportionment for Reliability Engineers
- Design Ramifications in Reliability Apportionment for Design Engineers
- Qualification-Reliability Test Plan
- Malfunction Reporting, Analysis, and Corrective Action
- The Role of Manufacturing in Attaining Reliability
- Reliability for the Apollo Buyer
- Apollo Reliability Indoctrination and Motivation for Supplies

PREAWARD SURVEYS

During this reporting period the following preaward surveys were performed:

Data Processing Equipment

Beckman Instrument Corporation	Fullerton, California
The Bendix Corporation, Pacific Division	North Hollywood, California
Consolidated Electric	Monrovia, California
Electronie Engineering Corporation (EECO) of California	Santa Ana, California
Electro Mechanical Research, Corporation	Sarasota, Florida
Radiation, Inc.	Melburn, Florida

Telecommunication System (Telemetry, Antenna, Radome)

Airborne Instrument Laboratories	Long Island, New York
Brunswick Corporation Defense Division	Marion, Virginia
Canoga Electronics	Van Nuys, California
Darn & Margolin	Long Island, New York
Electronics Specifications	Los Angeles, California
ITT Federal Laboratories	Nutley, New Jersey
Melpar, Incorporation	Falls Church, Virginia
McDonnell Aircraft	St. Louis, Missouri
Norair	Hawthorne, California
Rantel Corporation	Calabasas, California
Transco Products	Los Angeles, California

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Table 20. Procurement Specification Contributions, 1 April through 30 June 1962

Spec. No.	Title	Date
MC 2840013	Valve, Solenoid Actuated, Nitrogen Tetroxide Feed Control	April 13
MC 282-0005	Pressure Vessel, Helium (48-inch Nominal ID)	April 11
MC 282-0002	Pressure Vessel, Helium (10-inch Nominal Diameter)	April 11
MC 282-0007	Tank, UDMH/Hydrazine - Positive Expulsion (Cylindrical)	April 16
MC 282-0006	Tank, Nitrogen Tetroxide - Positive Expulsion (Cylindrical)	April 16
MC 282-0008	Tank, UDMH/Hydrazine-Positive Expulsion (16-1/4 nominal diameter)	April 16
MC 901-0008	System, Hypergolic Propellant Utilization	May 16
MC 284-0020	Service-Module Propulsion-Pressurization System	May 23
MC 284-0022	Service-Module Propulsion-Pressurization System	May 23
MC 286-0005	Reaction Control Oxidizer-Feed System	May 25
MC 286-0003	Reaction Control Fuel-Feed System	May 25
MC 286-0009	Rocket Engine, Apollo Service Module Propulsion System	May 29
MC 273-0018	Coupling, Nitrogen Tetroxide Tank, Fill and Drain Disconnect	June 14
MC 282-0004	Tank, Nitrogen Tetroxide, Positive Expulsion (Spherical)	June 28
MC 364-0001	Apollo Command Module Heat Shield Ablative Panels	May 19
MC 901-0012	Stabilization and Control Subsystem	June 14

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SUBCONTRACTOR REPORTS REVIEWED

Table 21. Subcontractor Reports Reviewed by Reliability Engineers

Report No.	Subject	Source
SS-1000-R	System Specifications Environmental Control Subsystem	AiResearch
SS-1001-R	Test Plan	AiResearch
SS-1002-R	GSE Performance and Interface Specifications	AiResearch
SS-1007-R	Maintenance Plan ECS and Associated GSE	AiResearch
SS-1008-R	Revised Manufacturing Plan	AiResearch
SS-1010-R	Quality Control Plan	AiResearch
SS-1014-R	ECS Design Criteria Specification	AiResearch
SS-1020-R	Program Plan ECS	AiResearch
AR 101-3	Monthly Progress Report, 15 March 1962 to 15 April 1962	Collins Radio
AR 101-4	Monthly Progress Report for the Apollo Communications and Instrumentation Subsystem Covering 15 April 1962 to 15 May 1962	Collins Radio
AR 103-2	Preliminary System Specification for the Apollo Telecommunications System	Collins Radio
AR 105-2	GSE Performance and Interface Specification	Collins Radio
AR 107-2	Test Plan for the Apollo Telecommunications System	Collins Radio

Table 21. Subcontractor Reports Reviewed by Reliability Engineers (Cont)

Report No.	Subject	Source
AR 108-2	Part I of the Reliability Program Plan for Apollo Telecommunications System	Collins Radio
AR 110-2	Inspection, Measuring and Test Equipment Procedures	Collins Radio
AR 111-2	Program Plan for Apollo Communications and Data Subsystem	Collins Radio
AR 112-2	Manufacturing Plan	Collins Radio
AR 113-1	Part II of the Reliability Program Plan for Apollo Telecommunications System	Collins Radio
AR 118-2	Quality Control Plan for the Apollo Communications and Instrumentation Subsystem, 4 June 1962	Collins Radio
AR 120-1	Quarterly Progress Report for the Apollo Telecommunications System	Collins Radio
AR 121-1	Quarterly Status Report	Collins Radio
AR 123-1	Preliminary Equipment Specification for the VHF FM Transmitter	Collins Radio
AR 124-1	Preliminary Equipment Specification for the VHF Recovery Beacon	Collins Radio
AR 125-1	Preliminary Equipment Specification for the VHF Antenna Switch	Collins Radio
AR 126-1	Preliminary Equipment Specification for the DSIF Power Amplifier	Collins Radio
AR 127-1	Preliminary Equipment Specification for the VHF AM Transceiver	Collins Radio
AR 128-1	Preliminary Equipment Specification for the C-Band Radar Transponder	Collins Radio

Table 21. Subcontractor Reports Reviewed by Reliability Engineers (Cont)

Report No.	Subject	Source
AR 129-1	Preliminary Equipment Specification for the Multiplexer	Collins Radio
AR 130-1	Preliminary Equipment Specification for the DSIF Transponder	Collins Radio
AR 131-1	Preliminary Equipment Specification for the Telemetry System	Collins Radio
AR 132-1	Preliminary Equipment Specification for the HF Recovery Transceiver	Collins Radio
AR 133-1	Preliminary Equipment Specification for Controls and Displays	Collins Radio
AR 134-1	Preliminary Equipment Specification for the Audio Center	Collins Radio
AR 135-1	Preliminary Equipment Specification for the Clock	Collins Radio
AR 136-1	Preliminary Equipment Specification for the Instrument Recorder	Collins Radio
AR 136-2	Equipment Specification for the Data Storage Equipment of the Apollo Communications and Data Subsystem 25 June 1962	Collins Radio
AR 137-1	Preliminary Equipment Specification for the Discone Antenna	Collins Radio
AR 139-1	Preliminary Equipment Specification VHF FM Transmitter Unit Bench-Test Set of the Apollo Telecommunications System	Collins Radio
AR 140-1	Preliminary Equipment Specifications for the HF Recovery Transceiver Unit Bench-Test Set of the Apollo Telecommunications Systems	Collins Radio

Table 21. Subcontractor Reports Reviewed by Reliability Engineers (Cont)

Report No.	Subject	Source
AR 141-1	Preliminary Equipment Specification for the CB and Radar Transponder Unit Bench Test Set of the Apollo Telecommunications System	Collins Radio
AR 142-1	Preliminary Equipment Specification for the Audio Center Unit Bench-Test Set of the Apollo Telecommunications System	Collins Radio
AR 143-1	Preliminary Equipment Specification for the VHF AM Transceiver Unit Bench-Test Set of the Apollo Telecommunications System	Collins Radio
AR 144-1	Preliminary Equipment Specification for the Deep-Space Instrumentation Facility Unit Bench-Test Set of the Apollo Telecommunications System	Collins Radio
AR 146-1	Preliminary Equipment Specifications for the Aide Units of the Apollo Telecommunications System	Collins Radio
AR 147-1	Preliminary Equipment Specifications for the Discone Antenna Unit Bench-Test Set of the Apollo Telecommunications System	Collins Radio
AR 148-1	Preliminary Equipment Specifications for the Multiplexer Unit Bench-Test Set of the Apollo Telecommunications System	Collins Radio
AR 149-1	Preliminary Equipment Specifications for the System Test Equipment of the Apollo Telecommunications System	Collins Radio
AR 151-1	Interim Report on the Status of Modulation Study for Project Apollo Deep Space Communications	Collins Radio

Table 21. Subcontractor Reports Reviewed by Reliability Engineers (Cont)

Report No.	Subject	Source
W 3686 WA	Vacuum Testing Requirements	Collins Radio
588-M-1	Reliability Program	Lockheed
588-M-4	Design Criteria Specification Launch Escape Motor	Lockheed
588-M-5	Preliminary Equipment Specification Launch Escape Motor	Lockheed
588-M-6	Test Plan	Lockheed
588-M-8	Lockheed Propulsion Corporation Qualification Reliability Test Plan on Launch Escape Motor	Lockheed
588-M-11	Quality Control Plan	Lockheed
588-M-13	End Item Acceptance Test Plan	Lockheed
A-1002	Program Plan	Marquardt
A-1007	Test Plan	Marquardt
A-1008	End Item Acceptance Test Plan	Marquardt
A62750A1(1)	Criteria Specifications	Minneapolis-Honeywell
A62751B(2)	Facilities Plan Stability and Control System	Minneapolis-Honeywell
A62751H1(1)	End Item Test Plan	Minneapolis-Honeywell
A62760A(1)	Flight Crew Performance Specification	Minneapolis-Honeywell
A62760A3(1)	Life System Display and Control Provisions	Minneapolis-Honeywell

Table 21. Subcontractor Reports Reviewed by Reliability Engineers (Cont)

Report No.	Subject	Source
A62768B(2)	Quality Control Plan-Stability and Control System	Minneapolis-Honeywell
2518	GSE Specification	Northrop Ventura
2519 A	Design Criteria Specification	Northrop Ventura
2523 A	Revised Test Plan	Northrop Ventura
2523 B	Revised Test Plan	Northrop Ventura
2526	Reliability Demonstration Plan	Northrop Ventura
2529	End Item Acceptance Test Plan	Northrop Ventura
2531	Northrop Ventura Quality Control Plan Earth Landing System	Northrop Ventura
59303	Equipment Specification	Northrop Ventura
PWA 2054	Test Plan	Pratt and Whitney
PWA 2055	Reliability Program Plan	Pratt and Whitney
PWA 2057	Reliability Test Plan	Pratt and Whitney
PWA 2059	Quality Control Plan	Pratt and Whitney
PWA 2079	End Item Test Plan	Pratt and Whitney
A 004	Test Plan	Thiokol
A 006	Reliability Assurance Program Plan	Thiokol
A 011	Materials, Parts and Process Specifications	Thiokol

PROPOSALS REVIEWED

Table 22. Proposals Reviewed by Reliability Personnel

Number	Subject	Source
1867	Apollo R & D Telemetry Antenna System; Section II Management Proposal, Section III Technical Proposal	Pantec
1877	Apollo R & D Beacon Antenna System; Section II Management Proposal, Section III Technical Proposal	Pantec
J-2355	Apollo R & D Beacon Antenna System; Section III Technical Proposal	Airborne Instruments Lab.
J-2356	Apollo Recovery Antenna System; Section II Management Proposal, Section III Technical Proposal	Airborne Instruments Lab.
J-2357	Apollo R & D Telemetry Antenna System; Section II Management Proposal, Section III Technical Proposal	Airborne Instruments Lab.
N 30026	Apollo Recovery Antenna System; Section II Management Proposal, Section III Technical Proposal	General Electric Co.

Table 22. Proposals Reviewed by Reliability Personnel

Number	Subject	Source
N-30027	Apollo R & D Telemetry Antenna System; Section II Management Proposal, Section III Technical Proposal	General Electric Co.
TP 1056	Apollo R & D Beacon Antenna System; Section II Management Proposal, Section III Technical Proposal	Transco

TRIPS AND MEETINGS

Table 23. Trips and Meetings, April through June 1962

Discussion	Participants	Date
Technical coordination meeting	Minneapolis-Honeywell NAA	April 3
Reliability requirements for the Apollo fuel cell	Pratt and Whitney NAA	April 5 - 6
Environmental control system	NASA NAA/S&ID	April 10
Reliability program plan	AiResearch NAA/S&ID	April 11
Discuss analysis, design and installation problems encountered on Project Mercury	McDonnell Aircraft Corp NAA/S&ID	April 16
Relay versus solid state electrical sequencer design	Rocketdyne NAA/S&ID	April 17

Table 23. Trips and Meetings, April through June 1962 (Cont)

Discussion	Participants	Date
Reliability apportionment to guidance and navigation subsystem	NASA NAA/S&ID MIT	April 18
GSE checkout concept for boilerplate and prototype equipment	Minneapolis-Honeywell NAA/S&ID	April 19 - 21
On-site analysis of personal facilities, test and tooling equipment	AVCO-RAD NAA/S&ID	April 29 - May 2
Review existing Mercury reliability data	McDonnell Aircraft Corp NAA/S&ID	April 30 - May 2
Guidance reliability meeting	NASA NAA/S&ID MIT	May 1 - 10
Test plan and statistical testing	Collins Radio NAA/S&ID	May 3
GSE checkout concept for bench maintenance equipment	Collins Radio NAA/S&ID	May 15 - 16
Review of Apollo qualification-reliability test plan	NASA NAA/S&ID	May 17 - 18
Bench maintenance and checkout equipment reliability criteria	Northrop Ventura NAA/S&ID	May 25
GSE checkout and reliability requirements	Aerojet NAA/S&ID	May 25
Prototype stabilization and control system checkout concept	Minneapolis-Honeywell NAA/S&ID	May 28 - 29
Project Apollo environmental control system reliability	AiResearch NAA/S&ID	May 29

Table 23. Trips and Meetings, April through June 1962 (Cont)

Discussion	Participants	Date
GSE requirements	Marquardt NAA/S&ID	June 5
Motor case design	Thiokol NAA/S&ID	June 7 - 8
GSE bench maintenance concept	AiResearch NAA/S&ID	June 12
Reliability requirements for GSE	Minneapolis-Honeywell NAA/S&ID	June 19, 21 - 22
S-II reliability program and Apollo presentation	Marshall Space Center NASA NAA/S&ID	June 24 - 29
Apollo GSE general reliability requirements	AiResearch NAA/S&ID	June 25
Apollo reliability plan	NASA NAA/S&ID	June 25
Apollo reliability plan	NASA NAA/S&ID	June 25 - 26
Review of qualification-reliability test plan	NASA NAA/S&ID	June 26
Definitive contract firm-cost proposal field analysis	AVCO-RAD NAA/S&ID	June 27 - 29
Discuss system analysis techniques and S&ID's reliability mathematical models	NASA NAA/S&ID	June 27
General reliability criteria for prototype stabilization control and GSE equipment	Northrop Ventura NAA/S&ID	June 28

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II. PLANNED ACTIVITIES

During the July through September 1962 quarter, the following studies will be conducted.

SPACECRAFT RELIABILITY

During the next quarter, spacecraft reliability studies will be expanded to consider other systems of the total spacecraft, including the LEM configuration and the use of LEM equipment in accomplishing alternate modes.

LAUNCH ESCAPE SUBSYSTEM

During the next reporting period, emphasis will be placed upon an overall system apportionment and failure mode analysis for interaction of the launch escape subsystem within the over-all Apollo vehicle. Emphasis will be placed upon implementing the redirected system concept through employment of a pitch control motor for thrust vector control.

First development firings will begin and data will be utilized, wherever applicable, for reliability evaluations.

Subcontractor monitoring will be amplified as the development program is implemented. The liaison meetings will include design reviews and audits of the reliability program.

FUEL CELL REAPPORTIONMENT

During the next reporting period a reapportionment of the fuel cell module consistent with the reliability objective of 0.971 will be completed. A more detailed failure mode analysis will be made utilizing early development test data and more refined design details. Expansion of the qualification-reliability test plan will be accomplished along with initiation of development tests on fuel cell hardware. Emphasis will be placed upon establishing a firm manufacturing technique for the production fuel cell electrodes.

WEIGHT REDUCTION STUDIES

Reliability studies are underway in support of a weight reduction investigation being conducted by Apollo Engineering. Areas of investigation include the possible elimination of major redundancy, on-board spares,

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in-flight test provisions, controls and displays, and recovery back-up provisions. The ramifications of exclusions on reliability will be quantitatively determined, as will compensating approaches such as parts improvement programs, redundancy at the part level, decrease in stresses through the use of higher derating factors, alternate modes employing other subsystems, and simplification within various circuits and equipment.

RE-APPORTIONMENT OF RELIABILITY OBJECTIVES

As a result of configuration and lunar landing concept changes, the original apportionment of NASA assigned reliability and crew survival objectives is no longer valid. Studies are underway to re-apportion these objectives, taking into consideration current concepts and configurations.

Reliability logic diagrams have been constructed for the various phases of operation employing the LEM concept. Seven primary-mode and abort-mode logic networks are currently defined. Similar re-apportionments will be conducted employing the spacecraft for direct lunar landing.

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REFERENCES

1. Compilation of Component Field Reliability Data Useful in Systems Reliability Design, WADD TR-60-330 (Secret).

2. Documentation Requirements for the Apollo Fuel Cell System, SID 62-332.

3. Earles, D.R., Reliability Application and Analysis Guide, The Martin Company, MI-60-54, Revision 1, July 1961.

4. Martin Handbook of Generic Failure Rates, The Martin Company.

5. NASA Project Apollo Spacecraft Development Statement of Work, Part III, Revised.

6. NEL Reliability Design Handbook, Naval Electronics Laboratory, USN.

7. Pratt & Whitney Aircraft Service Records, Pratt & Whitney.

8. Preparation of Test Reports, Mil-T-9107.

9. Qualification Reliability Test Plan, SID 62-204.

10. Rome Air Development Center Reliability Notebook, Supplement 1.

11. Format for Test Procedure for Reproduction and Inspection for Aircraft Electronic Equipment, Mil-T-18303.

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